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CONTENTS

Studies on Redox Potential of Marine Sediments	By Claude E. ZoBell	477
Miocene Conglomerates of Puente and San Jose Hills, By A. O. Woodford, T. G. More		514
Gramp's Field, Archuleta County, Colorado By	W. A. Waldschmidt	561
Tectonic Framework of Northwestern South America By	Fritz E. Von Estorff	581
San Pedro Oil Field, Province of Salta, Northern Arg	gentina By Lyman C. Reed	591
GEOLOGICAL NOTES		
Stratigraphy Near Caborca, Northwest Sonora, Mexi By G. Arthur Cooper and		606
Age of Penters Chert, Batesville District, Arkansas	By Douglas M. Kinney	611
Conodonts from Triassic of Sinai (Egypt)	By D. B. Eicher	613
Asphaltic Sands Found to Occur in Oil Fields By D. B. Taliafe	770 and K. E. Stanfield	616
DISCUSSION		
Photography of Megafossils	By Floyd K. Beach	620
REVIEWS AND NEW PUBLICATIONS		
Recent Publications		625
THE ASSOCIATION ROUND TABLE		
Membership Applications Approved for Publication		629
MEMORIAL		
Albert Foster Crider	By C. L. Moody	633
Frank Marion Anderson	By C. M. Wagner	636
AT HOME AND ABROAD		
Current News and Personal Items of the Profession		640



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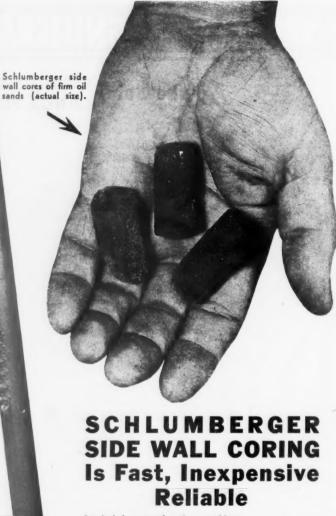
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Buried Pre-Cambrian Hills in Northeastern Barton County, Central Kansas

By ROBERT F. WALTERS

Transformation of Organic Material into Petroleum under Geologic Conditions

By BEN COX

Annual Reports and Minutes

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BULLETIN of the AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

APRIL, 1946

STUDIES ON REDOX POTENTIAL OF MARINE SEDIMENTS¹

CLAUDE E. ZoBELL² La Jolla, California

ABSTRACT

The redox potential of sediments may be used advantageously in the study and interpretation of the morphology, general nature, and chemical processes in unconsolidated sediments. The redox potential is believed to have a pronounced effect on the diagenesis of sedimentary materials, including the conversion of organic matter into petroleum.

The modern concepts of oxidation, reduction, and redox potentials are discussed. The redox potential is measured in volts and is expressed as an E_h value, E_h being the e.m.f. of an oxidation-reduction system referred to a standard hydrogen half-cell. The E_h of a system is a quantitative reduction system referred to a standard hydrogen market. The E_h of a system is a quantitative expression of its oxidizing or reducing intensity. Redox potential may be defined as the electron-escaping tendency of a reversible oxidation-reduction system, and thus is an intensity factor. The reducing or oxidizing capacity of sediments is independent of the redox potential, although there is a relation between the intensity and capacity factors. The pH and temperature at which measurements are made influence the redox potential of sediment samples.

The E_h of sediments, like the pH, can be measured either colorimetrically or electrometrically. A description of the methods of measuring the E_h of sedimentary materials helps to clarify the concepts of redox potentials. Methods of measuring the capacity as well as the intensity factor are

Data on more than 1,000 samples of bottom deposits indicate that each type of sediment has its own characteristic E_h and ρ H. E_h values ranging from +0.350 to -0.500 volt have been observed in samples of recent sediments in which the pH ranged from 6.4 to 9.5. As a very general rule, the pH of sediments increases with core depth and the E_h decreases, or conditions become more alkaline and more reducing with core depth. The reducing capacity decreases with core depth.

Positive Eh values are generally characteristic of bottom deposits which are well oxygenated, those which consist of coarse sediments, or those which are poor in organic matter. Negative E_h values are characteristic of bottom deposits rich in organic matter and which consist largely of fine sediments. An abundance of readily decomposable organic matter appears to promote reducing conditions. In the presence of organic matter, bacteria and allied microorganisms create reducing conditions. Such conditions are maintained by certain organic compounds, ferrous iron, reduced manganese, hydrogen sulphide, and other inorganic constituents of sediments.

¹ Contribution from the Scripps Institution of Oceanography, New Series No. 279. Manuscript received, December 11, 1945.

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INTRODUCTION

The oxidation-reduction or redox potential is believed to have a pronounced effect upon the composition, chemical reactivity, diagenesis, color, biological population, and other properties of recent sediments. Being a quantitative measure of the tendency of a given system to oxidize or reduce susceptible substances, the redox potential of sediments provides a criterion as to whether certain constituents occur in an oxidized or a reduced state. For example, iron could be expected to occur in the metallic or ferrous state in a highly reducing environment, whereas it ordinarily would occur in the ferric state in an oxidizing environment. This applies to a large number of other reversibly oxidizable or reducible constituents of marine sediments, both organic and inorganic.

Besides indicating the state of such constituents, the redox potential of sediments indicates whether new materials being deposited are more likely to be oxidized or reduced. The solubility of such substances as iron, manganese, copper, and certain other reversibly oxidizable minerals is influenced by the redox potential. The state of both manganese and iron in marine sediments was found by Brujevicz (1937) to be a function of the redox potential. Pearsall and Mortimer (1939) report that the state of iron, sulphur, and certain nitrogen compounds in water-logged soils is influenced by the redox potential. Allgeier et al. (1941) find that the principal effect of the redox potential of lake deposits is on the content of ferrous iron, hydrogen sulphide, and organic matter. The redox potential of sediments is a most important factor in determining the stability and biochemical transformation of organic matter.

A good many chemical reactions which influence the diagenesis and morphology of sediments are influenced by the redox potential. According to Keaton and Kardos (1940), the redox potential of a soil may be used in the study and interpretation of the general nature of the chemical processes in the soil and the changes in these processes as affected by some external factor. Any chemical reaction which involves the exchange of electrons (and this is generally true of all oxidation and reduction reactions) will be influenced by the redox potential. The effect of redox potentials and reactions on soil morphology has been emphasized by the studies of Gillespie (1920), Remesow (1930), Herzner (1931), Willis (1932, 1934), Kononova (1932), Batjer (1934), Brown (1934), Bradfield et al. (1934), Kohnke (1934), Heintze (1934, 1935), Peech and Batjer (1935), Wartenburg (1935), Sturgis (1936), Burrows and Cordon (1936), Shibuya et al. (1936), Stephenson et al. (1938), Buehrer et al. (1939), Volk (1939a, b), Keaton and Kardos (1940), and others.

The fragmentary observations of Kusnetzow (1935a, b), ZoBell (1935, 1936), Brujevicz (1937, 1938), Hutchinson et al. (1939), and Allgeier et al. (1941) indicate that the redox potential of lacustrine or marine materials has a definite effect on the chemical composition and morphology of recent sediments.

The redox potential has much to do with determining the kinds, distribution, and physiological activities of bacteria and allied microorganisms in sediments,

and there are many ways in which the activities of microorganisms influence the diagenesis of sediments (ZoBell, 1942, 1943). Bacteria themselves appear to be the principal dynamic agents which affect the redox potential of soil and sediments. The redox potentials of biological systems have been extensively studied (Hewitt, 1936; Elema, 1932; Kanel, 1941; Axelrod and Johnson, 1939).

In addition to its multiple effects on the diagenesis of sediments, the redox potential is believed to influence the formation and preservation of petroleum. Highly reducing conditions favor the biochemical hydrogenation or reduction of organic matter, a process which tends to convert certain kinds of organic matter into petroleum hydrocarbons or substances which are more hydrocarbon-like than the parent substance. In oxidizing environments, organic matter is more likely to be carbonized or oxidized by microorganisms to carbon dioxide and water.

Porfiriev (1937) expressed the view that the same organic matter could have been converted into either coal or petroleum, depending on the mode of fossilization and whether conditions were oxidizing or reducing. According to Stutzer and Noé (1940) the redox potential of peat, which gives rise to coal, is qui e different from that of the sapropel from which petroleum is believed to be derived. Since preliminary observations indicate that petroleum occurs only in highly reducing environments, it is believed that the redox potential may prove to be a significant characteristic of source sediments. Detailed data on the redox potentials of sediments may make it possible to determine the more exact nature of the diagenetic processes in general.

The potential differences across the contacts of sandstone and shale, which Dickey (1943) calls "natural potentials" as differentiated from the potentials caused by electro-endosmosis and concentration differences, may be due in part to the redox potential of sedimentary rocks. While it may be far easier to measure the redox potentials of sediments (and such measurements are attended by many pitfalls) than to interpret the results, detailed studies of the redox potentials of source sediments seem to be indicated. This paper is devoted primarily to a discussion of the concepts of redox potentials and the methods of determining such potentials of sedimentary materials.

DEFINITIONS

Oxidation-reduction potential may be defined as a quantitative measure of the energy of oxidation or the electron-escaping tendency or fugacity of a reversible oxidation-reduction system. For short, it is often referred to as the redox potential and is commonly abbreviated O/R potential. It is sometimes called the reduction potential, the oxidation potential, or the electrode potential, although these terms are not necessarily synonymous. Throughout this paper, redox potential is used as synonymous with oxidation-reduction or O/R potential.

The redox potential is the degree of oxidation or reduction of a reversible O/R system, or it is a measure of how reducing or how oxidizing the system is with

reference to some standard. When referred to hydrogen, the redox potential is commonly expressed as E_h in terms of volts, E being the potential difference between the standard hydrogen electrode and the system of which the redox potential is being measured. In some respects the E_h of a system is analogous to the pH, and the two are closely related. Whereas the pH is an expression of the hydrogen-ion (H⁺) concentration, or the relative acidity or alkalinity of a system; the E_h is an expression of the tendency of a reversible redox system to be oxidized or reduced.

Unlike the pH scale, on which neutrality is defined as pH 7.0, there is no true neutrality on the E_h or redox potential scale. Likewise there are no readily definable upper or lower limits on the E_h scale as there are on the pH scale. While it is customary to regard the E_h values of the theoretical hydrogen and oxygen electrodes as the lower and upper limits respectively on the redox potential scale, there are numerous oxidizing agents such as acidic bichromate and persulfate, for example, which are more oxidizing than O_2 , and there are numerous systems which are more reducing than H_2 (cf. Hodgman, 1943, p. 1345).

The redox potential of a standard normal hydrogen electrode (a solution of H_2 at one atmosphere pressure and pH 0) is $E_h=0$ at 25°C. The theoretical oxygen electrode at pH 0 has been shown to be $E_h=1.23$ volts. As discussed later, the E_h is partly a function of the pH. At pH 7.0 the redox potential of the hydrogen electrode is $E_h-0.41$ volt. At pH 7.0 the redox potential of the oxygen electrode is $E_h+0.81$ volt.

According to early concepts, oxidation was regarded as a chemical reaction involving the addition of oxygen to an oxidizable substance such as ferrous oxide, for example:

2FeO + O → Fe₂O₃.

The reverse process, or the removal of oxygen, is reduction. Later it was learned that certain substances could be oxidized or reduced without oxygen being involved. For example, on heating in the absence of oxygen, ethane is oxidized to ethylene and hydrogen:

$$\begin{array}{c} CH_3 \\ | \\ CH_3 \end{array} + \text{heat} \rightarrow \begin{array}{c} CH_2 \\ | \\ CH_2 \end{array} + H_2.$$

In this case oxidation involves the loss of hydrogen. The reverse process, or the addition of hydrogen, is reduction. Thus reduction may be defined as the addition of hydrogen or the removal of oxygen, and oxidation may be defined as the addition of oxygen or the removal of hydrogen. However, certain substances may be oxidized or reduced without either oxygen or hydrogen being involved. For example, when treated with chlorine, ferrous chloride is oxidized to ferric chloride:

$$Fe^{++}Cl_{2}^{-} + Cl \rightarrow Fe^{+++}Cl_{3}^{-}$$

When written in the ionized form, it is observed that the oxidation of iron has

involved the exchange of an electron. An inspection of other oxidation or reduction reactions reveals that such reactions always involve the exchange of electrons regardless of whether oxygen or hydrogen is involved. If the iron system is considered alone, the reaction may be written:

$$Fe^{++} \rightarrow Fe^{+++} + e$$

where e represents an electron. It should be borne in mind that an electron is a negative charge. Substances or systems undergoing oxidation lose electrons while those undergoing reduction gain electrons. For every oxidation there must be a corresponding reduction.

PHYSICO-CHEMICAL CONSIDERATIONS

Since oxidation and reduction reactions are electronic migrations involving the exchange of electric charges, the intensity of redox reactions can be measured in terms of e.m.f., or electric potential differences. When an unattackable electrode (such as platinum or gold metal) is immersed in a reversible redox system, a potential difference is set up at the electrode which can be measured potentiometrically. The more highly oxidized a system is the higher will be the electrode potential, and the more reduced a system is the more negative will the potential be. Since we are dealing with reversible systems, the electrons may flow in either direction, depending on prevailing conditions. Consider the system of ferrous-ferric ions, for example:

(1)
$$Fe^{++} \rightleftharpoons Fe^{+++} + e_s$$

Applying the mass action chemical equilibrium equation, we get

(2)
$$\frac{(\mathrm{Fe}^{+++}) \times (e_s)}{(\mathrm{Fe}^{++})} = k$$

where e_s is the concentrations of free electrons in the system and k is a constant. The parentheses indicate activity concentrations. If e_s is increased, reaction τ proceeds from right to left, or ferric iron will be reduced to ferrous iron until equilibrium is established. If e_s in reaction τ is decreased, there is a tendency for ferrous iron to be oxidized to the ferric state.

An unattackable electrode immersed in the reversible redox system does not participate in the reaction but acts merely as an inert conductor of electrons to or from the system. Such an electrode can be considered to be a store of electrons of fixed concentration, e_m . Since the concentration or escaping tendency of electrons in the unattackable electrode, e_m , is different from that in the reversible redox system, e_s , a potential difference is set up at the electrode. It can be shown from physico-chemical considerations that the work done in transferring an equivalent of electrons from the redox system to the electrode is:

Osmotic work =
$$RT \ln (e_m) + RT \ln \frac{I}{(e_a)}$$

where R is the gas constant equal to 1.99 calories per degree, T is the absolute temperature and \ln is natural logarithms. The work is equal to the quantity of electricity transferred multiplied by the potential at which the transfer is made:

(4) Electrical work =
$$nEF$$

where n is the number of equivalents transferred, E is the potential at which the transfer is made, and F is the conversion factor, a faraday of electricity. Now combining equations 3 and 4, we get:

(5)
$$EF = RT \ln (e_m) + RT \ln \frac{I}{(e_s)}$$

and solving for the redox potential, E:

(6)
$$E = \frac{RT}{F} \ln (e_m) + \frac{RT}{F} \ln \frac{\mathbf{I}}{(e_s)}$$

Since the concentration of electrons (e_m) in the unattackable electrode is a constant, k_1 , equation (6) may be written:

(7)
$$E = k_1 + \frac{RT}{F} \ln \frac{1}{(e_s)}.$$

Now returning to equation (r) and making it applicable to reversible redox systems in general, rather than merely to the ferrous-ferric iron system, we may designate the reduced form of a system by Red. and the oxidized form by Ox. so that:

(8) Red.
$$\rightleftharpoons$$
 Ox. $+ n_e$

where n is the number of electrons. Making similar substitutions in equation (2) we get:

$$\frac{(Ox.) \times (e_s)}{(Red.)} = k.$$

Equation (9) may be rewritten:

$$(e_s) = k \frac{(\text{Red.})}{(\text{Ox.})}$$

and substituting this value for e_s in equation (7), we obtain:

(11)
$$E = k_2 + \frac{RT}{nF} \ln \frac{(Ox.)}{(Red.)}$$

where k_2 is a constant.

It is not possible to measure a single potential difference, E, at an electrode because this constitutes only a half-cell, but if the circuit is completed by including a standard half-cell, the e.m.f. of the completed cell may be measured. If the standard half-cell is fixed as a solution containing one atmosphere of hydrogen (H_2) and one normal hydrogion-ion (H^+) concentration, we have a normal hydrogen electrode which is the standard of reference. Electrode potentials referred to this standard are measured in volts and designated E_h .

 $E_h = E - k_3$, where k_3 is the potential of the normal hydrogen electrode. Then by substituting this value for E in equation (11):

(12)
$$E_h = k_2 + \frac{RT}{nF} \ln \frac{(\text{Ox.})}{(\text{Red.})} = k_3.$$

Now let $k_2-k_3=E_0$, a constant for the system:

(13)
$$E_h = E_0 + \frac{RT}{nF} \ln \frac{(Ox.)}{(Red.)}$$

This is the general electrode equation of Peters (1898). According to Clark (1928), R=8.31507 volt coulombs, T, the absolute temperature at 30°C.=303°, and F=96,500 coulombs. Substituting these values for a system in which two electrons are concerned (n=2), at constant pH the equation becomes:

(14)
$$E_{A} = E_{0} + \text{o.o3 log} \frac{\text{(Ox.)}}{\text{(Red.)}}$$

in which log represents Briggsian logarithms (ln x=2.302585 log x). E_h is measured in volts and E_0 is a constant for the system. (Ox.) and (Red.) are the concentrations of the oxidized and the reduced forms respectively of the redox substance. From equation (14) it is evident that the E_h increases as (Ox.) increases and as (Red.) decreases. When the redox substance or system is 50 per cent oxidized (Ox.)=(Red.) and $E_h=E_0$. In other words, E_0 is the redox potential of a system which is 50 per cent in the oxidized form and 50 per cent in the reduced form.

As is pointed out by Hewitt (1936),

When the value of E_0 of a system is known, it is possible to calculate the electrode potential at any degree of oxidation or reduction of the system; and, vice versa, the degree of oxidation can be calculated from the value of the electrode potential. Furthermore E_0 is a measure of the oxidation or reduction intensity level of a system and enables oxidizing and reducing agents to be graded in their oxidizing or reducing effects.

For example, a reversible O/R system of $E_0 = +0.1$ volt will oxidize a system of $E_0 = -0.2$ volt, but it will be oxidized by a system of $E_0 = +0.2$ volt. Measurements of the redox potential provide a quantitative method of grading different systems in order of their relative oxidizing or reducing tendencies. This is illustrated by the E_0 values of equimolar mixtures of metallic ions recorded in Table

I. The redox potentials or E_0 values of several redox systems are given by Getman and Daniels (1943) and Hodgman (1943).

Any system in Table I will tend to reduce equimolar concentrations of any other system which is more oxidizing, and *vice versa*, other things being equal. For example, a system consisting of equal parts of ferrous iron (Fe⁺⁺) and metallic iron (Fe) will tend to reduce a similar system of cupric (Cu⁺⁺) and cuprous (Cu⁺)

TABLE I

REDOX POTENTIALS OF METALLIC COUPLES AT AN EFFECTIVE CONCENTRATION OF 1 GRAM-ION PER 1000 GRAMS OF WATER, IN WHICH THE COMPONENTS ARE 50 PER CENT IN THE OXIDIZED AND 50 PER CENT IN THE REDUCED STATE AT 25°C. (AFTER GETMAN AND DANIELS, 1943).

Oxidized Component	Reduced Component	E_0 in $Volts$	Oxidized Component	Reduced Component	E ₀ in Volts
K+	K	-2.024	H++	H_2	0.000
Fe++	Fe	-0.441	Sn++++	Sn ⁺⁺	+0.13
Cr+++	Cr++	-0.400	Cu++	Cu+	+0.150
Co++	Co	-0.283	Fe+++	Fe ⁺⁺	+0.78
Ni ⁺⁺	Ni	-0.236	Ag+	Ag	+0.700
Sn ⁺⁺	Sn	-0.140	Ag+ Tl+++	Ag Tl+	+1.211
Pb++	Pb	-0.126	Co+++	Co++	+1.817

copper, and the copper system would oxidize the iron system. In this case the cupric-cuprous copper system would tend to oxidize metallic iron to ferrous iron but not to ferric iron, because the E_0 of the ferric-ferrous iron system (+0.783 volt) is higher than that of the cupric-cuprous copper system (+0.159 volt).

It should be emphasized that the redox potential is an *intensity* factor in the same sense that temperature and pH are intensity factors. The redox potential does not indicate the reducing or oxidizing capacity of a system any more than the temperature of a system indicates how many calories of heat it may contain, or any more than the pH of a system indicates its buffer capacity or titratable acidity. The reducing or oxidizing capacity of a system is a function of the quantity of electrons which may be involved in a reaction, whereas the redox potential or intensity factor is a measure of the electron escaping tendency. The capacity factor of a redox system is referred to as poise and is analogous to the buffer capacity of a hydrogen-ion system. It is important to consider both the intensity and capacity factors of redox systems, many of which have well-defined electrode potentials but are not well poised.

The following tabulation shows the analogies of O/R systems to other systems.

System	Intensity Factor	Quantity or Capacity Factor
Oxidation-reduction Acidity or basicity Electricity Hydraulics Heat	E_h pH E.M.F. or volt Hydrostatic head Temperature	Poise Buffer capacity or titratable acidity Coulomb or kilowatt-hour Volume or water Calories

EFFECT OF pH ON EA

The redox potential or E_h of sediments, as of most systems, is dependent on the hydrogen-ion activity or pH of the sediment. This is because of the effect of the pH upon dissociation constants, ionic equilibria, solubilities and stabilities of reactants, et cetera. Reversible O/R systems generally become more reducing with increasing pH. The following E_h values for a M/100 solution of potassium iodide-iodine were found at different pH values at $25^{\circ}C$.

$$p$$
H values 1.9 2.3 3.6 4.1 6.3 6.7 10.5 E_h (in volts) $+$ 0.189 $+$ 0.178 $+$ 0.064 $+$ 0.138 $-$ 0.075 $-$ 0.130 $-$ 0.370

Between pH 1.9 and 10.5 the E_h of the iodide-iodine system decreased by 0.065 volt for each pH unit increase. Clark et al. (1928) point out that while the E_h of simple reversible O/R systems ordinarily decreases by about 0.06 volt per pH unit increase at 25° to 30°C., the E_h/pH slope may vary widely from this value. For complex mixtures of oxidizing and reducing agents such as may occur in biological systems, soil, or marine sediments, the E_h/pH relationships may be extremely complicated. However, the fact that the effect of pH on E_h is complex does not imply that the effect is great. The E_h values of various colorimetric redox indicators at different pH values are given in Table III.

According to Peech and Batjer (1935), the oxidation of hydroquinone shows an E_h decrease of 0.059 volt for each unit increase in pH. The E_h of permanganate is 0.095 volt lower for each unit increase in pH. In the oxidation by dichromate the redox potential decreases by 0.138 volt per unit pH increase. These examples should suffice to illustrate that the effect of pH on the redox potential of sedimentary materials will depend on the nature of the oxidizing and reducing systems present in the sediment. Furthermore, as is pointed out by Peech and Batjer (1935), changes in pH may alter the ratio of the oxidant to reductant by inducing oxidation, chemical precipitation, and complex ion formation, so the ultimate effect of pH on the E_h may be very complicated indeed. These investigators found, however, that in spite of the complexity of the O/R systems in soils, the E_h became more negative by about 0.08 volt per unit increase in pH between pH 3 and 8.

In the soils and soil colloids studied by Kohnke (1934), the E_h became more negative by about 0.06 volt per unit increase in pH, but there was a departure from this relationship on the soil's standing, owing to a slow differential solvent action on oxidant and reductant. Most of the soils studied by Willis (1932) showed a decrease in E_h of 0.066 volt per unit increase in pH. Burrows and Cordon (1936) used a factor of -0.06 volt per unit pH change to correct the potentials observed in soils to pH 7.0. Heintze (1934) reports that the redox potentials of soils depend so closely on the pH value that the E_h and pH should not be considered separately. Herzner (1930), Remesow (1930), Vlew and Meyer (1932), and Buehrer et al. (1939) also emphasize the necessity of correcting for the pH of soil in measuring redox potentials. After finding E_h/pH slopes ranging from

0.058 to 0.101 volt, Volk (1939a) pointed out the necessity of determining the $E_h/p_{\rm H}$ relationships for each soil separately.

By adding hydrochloric acid or sodium hydroxide to samples of recent marine sediments suspended in de-aerated sea water in a closed system, it has been observed that the E_h becomes more negative by an average of 0.061 volt per unit increase in pH for the entire range between pH 3 and 10. However, the decrease in E_h per unit pH between pH 6 and 8 ranged from 0.026 to 0.038 volt. Between pH 8 and 9 the E_h/pH slope ranged from 0.081 to 0.117 volt.

The redox potential of four representative samples at different pH values are recorded graphically in Figure 1. The determinations were made in a closed sys-

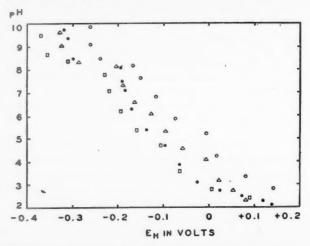


Fig. 1.— E_h of marine mud samples measured at different pH values. Squares used for sample No. 16-124, triangles for sample No. 40-18B, solid circles for sample No. 45-101, and open circles for sample No. 45-102.

tem to prevent the entrance of atmospheric oxygen or the loss of hydrogen sulphide or other volatile constituents which might influence the redox potential. Both E_h and pH measurements were made electrometrically by using platinum, calomel, and glass electrodes by methods described in subsequent paragraphs. The sharp break in E_h with change in pH between pH 8 and 9 is attributed primarily to the precipitation from solution of certain oxidizing components and the destruction of others.

The results obtained by determining the E_h of several samples of recent sediments at different pH values clearly demonstrate that there is no constant factor which can be applied to correct E_h readings to any given pH^{\bullet}_{a} value. In view of the complexity in the chemical composition of sediments, it is surprising that the average change in E_h per pH unit approximates so nearly the commonly

accepted theoretical value of -0.06 volt for simple systems at 30° C. Inasmuch as there is no simple relationship between the E_h and pH of sediments, the pH at which the E_h measurements were made must be specified in reporting results. The pH of the sample should be determined at the same time the E_h is being measured. A glass electrode is recommended for this purpose. The same calomel half-cell can be used for the pH and E_h determinations.

SIGNIFICANCE OF 'H

For a limited number of reversible redox systems in which the E_h varies with the pH in a known and simple manner, Clark *et al.* (1928) introduced the term rH to include both E_h and pH. The term rH was defined as the logarithm of the reciprocal of the partial pressure of hydrogen gas (P) in equilibrium with the system:

$$rH = \log \frac{1}{P}$$

Analogously, the pH is the logarithm of the reciprocal of the hydrogen-ion concentration (H⁺) of a system:

$$pH = \log \frac{1}{(H^+)}$$

At 30°C. the following relationship exists between the rH, E_h , and pH of certain simple redox systems:

$$rH = \frac{E_{h} + 0.06 pH}{0.03}$$

where 0.06 is the decrease in volts in the E_h per unit increase in pH and 0.03 is a constant for the system at 30°C. The rH and E_0 values of a few simple systems at pH 7.0 and 30°C. are recorded in the following tabulation.

System	rH	E_0
Oxygen electrode (theoretical)	41.0	+0.810 volt
Phenol blue chloride	21.6	+0.227
Methylene blue	14.4	+0.011
Indigo disulphonate	9.9	-0.125
Hydrogen electrode (theoretical)	0.0	-0.421

The term rH is convenient in the theoretical discussion of reversible systems having a known simple relationship between E_h and pH, but the use of the term is not justified for characterizing complex redox systems such as those of soil, sediments, or biological entities. Because of the indiscriminant use of the term rH where E_h or redox potential would be preferable, Clark (1928) has discouraged further employment of the term rH. Michaelis (1930) concurs with Clark in advising against further use of the concept of rH. The results of a good many

who have investigated redox potentials of soil and biological systems, however, have been given in terms of rH. The foregoing summary statement of rH is given only to aid in making the published results of such investigations comprehensible to students of the subject.

EFFECT OF TEMPERATURE ON EA

The temperature at which measurements are made has a small, though definite, effect on the E_h of a system as expressed by equation 13:

$$E_h = E_0 + \frac{RT}{nF} \ln \frac{(Ox.)}{(Red.)}$$

where T is the absolute temperature. For simple thermostable systems the E_h generally decreases with increasing temperature by an amount which varies with the system. Two well known redox systems have E_h values as follows at different temperatures.

Temperature	Standard Acetate H ₂ - Electrode (Michaelis, 1930)	N/10 KCl Calomel Half-Cell (Clark, 1928)
o°C.	-0.250 volt	_
10°C.	-0.259	-
20°C.	-0.268	+0.3375 volt
30°C.	-0.278	+0.3364
30°C. 40°C.	-0.287	+0.3349
50°C.	-0.296	+0.3326
60°C.		+0.3243

For complex systems, such as soil or sediments, the effect of temperature on the E_h is inconstant and capricious because of the multiple and unpredictable effects of temperature on the stability of reactants, dissociation constants, ionization, hydration, chemical reactivities, solubilities, etc. This is illustrated by the data in Table II which shows the E_h values of four different samples of marine mud measured at different temperatures ranging from o° to 90°C. With the

TABLE II $E_h \ {\rm Values} \ {\rm of} \ {\rm Four} \ {\rm Different} \ {\rm Marine} \ {\rm Mud} \ {\rm Samples} \ {\rm Measured} \ {\rm at} \ {\rm Different} \ {\rm Temperatures} \ {\rm Ranging} \ {\rm from} \ {\rm o}^{\rm o} \ {\rm Co}.$

Temperature	Mud No. S45-I	Mud No. S45-2	Mud No. S45-3	Mud No S45-4
	volts	volts	volts	volts
o°C.	-o.181	-0.105	-0.118	-0.070
100	-o.182	-0.003	-0.123	-0.062
20°	-0.192	-0.082	-0.132	-0.053
30°	-0.198	-0.080	-0.155	-0.042
40° 50° 60°	-0.208	-0.082	-0.176	-0.032
50°	-0.215	-o.o88	-0.203	-0.023
60°	-0.233	-0.087	-0.228	-0.017
70° 80°	-0.278	-0.088	-0.240	-0.017
80°	-0.292	-0.000	-0.283	-0.025
90°	-0.308	-0.008	-0.324	-0.041

electrodes in place the mud samples in a closed system were cooled to $o^{\circ}C$. in a salt-ice bath. After approaching equilibrium at $o^{\circ}C$., the E_h was read. Then the temperature was increased by increments of $10^{\circ}C$. every 5 minutes while recording the observed E_h values.

COLORIMETRIC REDOX POTENTIAL INDICATORS

Several different compounds are known which have one color when in the oxidized state and another color when in the reduced state. Some of these dyes have been proved useful in estimating the redox potential of certain systems in much the same manner as colorimetric indicators are used for pH determinations. Colorimetric indicators, however, are generally not nearly as reliable for measuring E_h as the indicators used in pH determinations are for their purpose.

One of the commonest colorimetric E_h indicators is methylene blue whose E_0 value is 0.00 volt at pH 7.3 and 30°C. By applying equation 14:

$$E_h = E_0 + \text{o.o3} \log \frac{\text{(Ox.)}}{\text{(Red.)}}$$

the following range of E_h values are obtained for different degrees of oxidation of methylene blue.

(Ox.)	(Red.)	E_h	Color of Methylene Blue
Per Cent	Per Cent	Volts	
99	1	+0.060	Almost full color
98	2	+0.051	
95	5	+0.038	
90	10	+0.020	
80	20	+0.018	
70	30	+0.011	
50	50	+0.060 Almost full of the color colo	Half color
30	70	-0.011	+0.060 Almost full color +0.051 +0.038 +0.029 +0.018 +0.011 0 Half color -0.011 -0.029 -0.029 -0.038 -0.051
20	80	-0.018	
10	90	-0.020	
5		-0.038	
2	95 98		
I	99	-0.060	Almost colorless

It is apparent from the foregoing data that if a little methylene blue is added to a redox system at pH 7.3 and 30°C., the persistence of any blue color indicates that the redox system is more oxidizing than $E_h = -0.060$ volt. A partial reduction of the methylene blue (less than full color) indicates that the redox system is less oxidizing than $E_h = +0.060$ volt. By comparison with methylene blue standards ranging from r to 99 per cent oxidation, it may be possible to estimate the E_h of the redox system with a fair degree of precision, provided the E_h is within the range of the colorimetric indicator and other prerequisite conditions are realized.

The useful range of a colorimetric redox indicator depends on its E_0 , this being the potential of the dye when 50 per cent in a reduced condition. For practical purposes the useful range extends about 0.05 volt above and 0.05 volt below its

 E_0 value. Various dyes having E_0 values ranging from as low as -0.4 volt to as high as +0.4 volt have been studied by Clark *et al.* (1928), Michaelis (1930), Cohen and Phillips (1929), Michaelis and Eagle (1930), Cohen and Priesler (1931) Clark and Perkins (1932), Letort (1932), Stiehler *et al.* (1933), Hewitt (1936), and Davis (1942). Several redox potential indicators are listed in Table III. It will be observed that the E_0 of each is influenced by the pH. The E_0 values at intermediate pH values can be approximated by interpolation.

TABLE III

 E_0 Values in Volts of Redox Potential Indicators at 30°C. and Different pH (from Clark et al., 1928, Clark, 1928, Cohen and Phillips, 1929, Cohen and Preisler, 1931, Clark and Perkins, 1932, Stiehler et al., 1933, and Hewitt, 1936).

Indicator	pH 5.0	pH 6.0	pH 7.0	pH 8.0	pH 9.0
m-Bromophenol indophenol	+0.374	+0.311	+0.248	+0.170	+0.102
o-Chlorophenol indophenol		+0.301	+0.233	+0.155	+0.082
Phenol indophenol	*	+0.286	+0.227	+0.155	+0.083
Phenol blue	+0.365	+0.200	+0.224	+0.163	+0.001
2:6-Dichlorophenol indophenol	+0.366	+0.205	+0.217	+0.150	+0.080
m-Cresol indophenol		+0.272	+0.208	+0.148	+0.076
o-Cresol indophenol	*	+0.256	+0.191	+0.130	+0.057
Thymol indophenol		+0.233	+0.174	+0.110	+0.041
m-Toluylenediamine indophenol	+0.195	+0.157	+0.125	+0.088	+0.037
Toluylene blue	+0.221	+0.162	+0.115	+0.082	+0.051
Thionine (Lauth's violet)	+0.138	+0.004	+0.062	+0.030	-0.001
Cresyl blue	+0.149	+0.080	+0.047	+0.015	-0.016
Gallocyanine		+0.080	+0.021	-0.037	-0.005
Methylene blue	+0.101	+0.047	+0.011	-0.020	-0.050
Toluidine blue	+0.087	+0.042	-0.005	-0.047	-0.099
Janus green (blue-red)	+0.050	+0.002	-0.035	-0.080	-0.115
Indigo tetrasulphonate	+0.065	+0.006	-0.046	-0.083	-0.114
Methyl capri blue	+0.038	-0.021	-0.060	-0.003	-0.123
Indigo trisulphonate	+0.032	-0.028	-0.081	-0.121	-0.152
Indigo disulphonate	+0.010	-0.069	-0.125	-0.167	-0.100
Gallophenine	-0.003	-0.077	-0.142	-0.202	-0.263
Brilliant alizarine blue	-0.040	-0.112	-0.173	-o.226	-0.279
Phenosafranine	-0.159	-0.219	-0.252	-0.283	-0.313
Tetramethyl phenosafranine	-0.156	-0.225	-0.273	-0.305	-0.336
Safranine T	-0.198	-0.250	-0.280	-0.318	-0.348
Neutral red	-0.204	-0.275	-0.325	-0.380	-0.435
Rosindone sulphonate No. 6	-0.287	-0.338	-o.385	-0.441	-0.508
Hydrogen electrode (theoretical)	-0.300	-0.361	-0.421	-0.481	-0.541

[•] Unstable in this region of pH.

The application of the data on the redox potential of reversible dyes to the estimation of the redox potential of a system is simple. Suppose it is found by colorimetric comparison that a solution of thionine, for example, is 30 per cent reduced by a system having a pH of 6.5. By interpolating it is found that the E_0 value of thionine at pH 6.5 is +0.078 volt. Now by substituting these numerical values in equation (14), we get:

$$E_h = 0.078 + 0.03 \log \frac{70}{30} = + 0.089 \text{ volt,}$$

this being the redox potential of a thionine solution which is 70 per cent in the oxidized state, or the E_h of the system which affects a 30 per cent reduction of thionine is ± 0.089 volt. This can be checked with other dyes in the proper range.

Besides possessing the proper potential range and being reversible, a satisfactory colorimetric redox potential indicator should have a sharp color end-point and should be stable in aqueous solutions. Such an indicator should have a maximum tinctorial effect with a minimum poising effect, and it should come to equilibrium with the redox system in a short time. It may be difficult or impossible to estimate the redox potentials of poorly poised sediments with colorimetric indicators. A further complicating factor is the fact that some sediments adsorb certain dyes, thereby invalidating their use as redox indicators. Furthermore the opacity or intense color of aqueous suspensions of some sediments interferes with the observation of colorimetric indicators.

In spite of the shortcomings of colorimetric indicators, however, they have been proved useful in characterizing samples of recent sediments. Kusnetzow (1935a) investigated the redox potential of lake water and mud by a colorimetric method, which he described as being superior to the electrometric method.

REDUCING CAPACITY OF SEDIMENTS

Redox dyes can be used to estimate the reducing capacity as well as the redox potential or reducing intensity of sediment samples. This is done by titrating a measured quantity of sedimentary material suspended in de-aerated water in a closed system. The amount of dye decolorized by the sample is indicative of the reducing capacity of the sediment at the $E_{\rm A}$ of the particular dye being used. For example, aliquot parts of a representative sample of recent marine sediments having a $p{\rm H}$ of 7.0 in an aqueous suspension were found to reduce M/10,000 solutions of dyes at $25^{\circ}{\rm C}$. as follows.

Dye	Eo of Dye at pH 7.0	m.e. of Dye Reduced
Neutral red	-0.325 volt	0.0
Phenosafranine	-0.252	0.8
Indigo disulphonate	-0.125	2.5
Methylene blue	+0.011	3.2
Phenol blue	+0.224	5.7

These data indicate that, while the E_h of the sample was in the neighborhood of -0.252 volt, only about 1/7 of the constituents were this reducing as compared with the constituents which reduced phenol blue having an E_0 of +0.224 volt at pH 7.0.

Sediments contain a large number of redox systems covering a wide range of reducing intensity. Some redox systems in sediments may be only slightly reducing relative to oxygen, whereas others may be extremely reducing. In fact, as is elaborated on the following pages, it is not uncommon to find recent marine sediments which are more reducing than the theoretical hydrogen electrode, or

which have E_h values more reducing than -0.421 volt at around pH 7.0 and 25° C. In such sediments, however, only a small fraction of the reducing constituents are responsible for the hydrogen overvoltages. In other words, the reducing capacity of the sediments in the range of hydrogen overvoltages may be relatively low in spite of the extremely high reducing intensity.

It may be significant that, in general, the more highly reducing the sediments the lower is the redox capacity. Significant, too, is the fact that in most of the core samples which we have studied stratigraphically, the reducing intensity or redox

TABLE IV

Redox Potential (E_h) , pH, and Reducing Capacity (Milli-Equivalents of Methylene Blue Reduced per Gram) of Different Strata of a Mud Core Collected from the Ocean Floor near San Diego, California, Where the Water Depth was 1650 Feet. The Number of Viable Bacteria per Gram (We, Weight) as Determined by Plating Procedures is also Given.

Bacteria per Gram	m.e. Methylene Blue Reduced	pH	E _h in Volts	Core Depth in Inches
63,000,000	18	7.8	-0.072	0-2 .
1,900,000	14	7.5	-0.135	2-4
900,000	11	7.4	-0.163	6-8
65,000	8	7.6	-0.207	10-12
40,000	7	7.8	-0.228	18-20
2,800	8	7.8	-0.231	24-26
7,200	5	7.8	-0.250	30-32
4,100	4	7.9	-0.241	36-38
600	4	7.8	-0.278	48-50
1,600	3	7.0	-o.286	60-62
400	3	7.9	-0.264	72-74
700	4	7.9	-0.303	84-86
600	4	7.9	-0.280	96-98

potential increases throughout the first few feet with core depth or age of the sediment while the reducing capacity decreases with core depth (ZoBell and Anderson, 1936). Changes with depth in the reducing capacity as well as the reducing intensity are greatest in the topmost foot or two of recently deposited sediments, below which depth the redox characteristics of the sediments do not change greatly with depth. At depths exceeding five to ten feet, changes in the redox potential with increasing depth are generally no greater than can be accounted for by the inaccuracies of sampling and measurements. Data from a representative core are given in Table IV.

ELECTROMETRIC MEASUREMENT OF EA

The electrometric method of measuring the redox potential of sediments is much more precise than colorimetric methods, the technique is simpler, and the results are somewhat easier to interpret. As a matter of fact, it has proved to be by far easier to measure the redox potentials of sedimentary materials than it is

to interpret the results. The apparatus for electrometric measurements is simple, consisting essentially of an electron-valve potentiometer, a standard half-cell, and an unattackable electrode. The apparatus in its simplest form is represented diagrammatically in Figure 2, which shows a platinum electrode (PT) and a calomel half-cell (HC) immersed in the redox system in a rubber-stoppered bottle. The platinum electrode and calomel half-cell are connected,

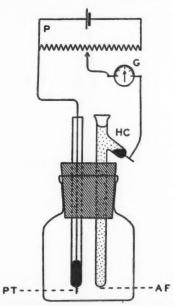


Fig. 2.—Assembled apparatus for electrometric measurement of redox potential of bottom deposits. Thermionic-valve potentiometer, P, and sensitive galvanometer, G, are connected by means of insulated copper wire with platinum electrode, PT, and calomel half-cell, HC. Electrodes are held in place by two-hole rubber stopper in squat, wide-mouthed bottle which contains sample of bottom deposit. AF is asbestos fiber fused in bottom of side-armed tube to provide for electrolyte bridge between sample and half-cell which is filled with saturated solution of potassium chloride.

preferably with flexible insulated wire, to the potentiometer (P) and the galvanometer (G).

In the type of half-cell illustrated in Figure 2 a chemically clean asbestos fiber (AF) is fused in the bottom of a glass tube to provide an electrolyte bridge between the half-cell and the redox system. The half-cell itself is filled with a saturated solution of potassium chloride after placing a drop of mercury and a little calomel (HgCl) in the side arm. Electric contact is made with the mercury by means of a platinum wire which is sealed extending through the bottom of the side arm. Additional details on the construction of the calomel electrode and

asbestos salt bridge are given by ZoBell and Rittenberg (1937). The reader is also referred to Michaelis (1935) for a detailed description of electrodes and other apparatus employed in measuring redox potentials.

The cross section of a simply constructed calomel half-cell or electrode is given in Figure 3. An asbestos fiber (AF) is fused through the bottom of a piece

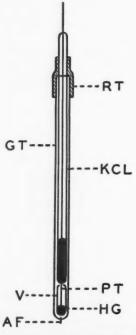


Fig. 3.—Cross section of simple calomel half-cell suitable for E_h or pH measurements. RT is short length of rubber tubing which secures inner platinum electrode, PT, to glass tube, GT. In bottom of glass tube is small vial, V, which contains drop of mercury, HG, a little calomel paste, and saturated KCl solution. Small opening at top of vial permits insertion of inner platinum electrode. Outer glass tube is filled with saturated KCl solution which very slowly leaks through asbestos fiber, AF, fused in bottom of tube.

of glass tubing (GT) having a diameter of 5 mm. Next a short vial (V) made from a piece of somewhat smaller glass tubing is introduced in the first glass tube after placing a drop of mercury and a little calomel in the vial. Electric contact is made with the mercury through a platinum electrode (PT), which is inserted in the glass tube. The glass tube and vial are then filled with a saturated solution of potassium chloride (KCI). The tube may be stoppered with a short length of snugly fitting rubber tubing (KCI).

Clark (1928) gives the following potentials for saturated calomel half-cells at different temperatures as referred to normal hydrogen electrodes.

Temperature 15°C. 20°C. 25°C. 30°C. 37°C. Potential in volts 0.252 0.249 0.246 0.242 0.236

These values are added to the potentials observed with the saturated calomel half-cell in order to obtain the value of E_h for the system.

Platinum has been proved most suitable for the fabrication of unattackable electrodes. It is chemically inert for practical purposes and does not participate in the O/R reaction except as a conductor of electrons. A piece of plain, bright, 22 B & S gauge platinum wire about 2 cm. long is fused in the end of a glass tube. A little mercury is placed in the glass tube, into which an amalgamated copper wire is dipped to connect with the potentiometer. A better electrode results from fusing the platinum wire to the copper wire conductor before fusing the platinum wire in the end of a small bore glass tube.

Experiments with coiled platinum wire electrodes of different lengths and with platinum foil electrodes have shown that the area of platinum exposed to the redox system is not important in well poised water-saturated systems. In order to insure good contact with the redox system, the electrodes are made so that about 1 cm. of 22 gauge platinum wire protrudes from the glass. In certain cases when the wire has been broken off by excessive manipulation, such electrodes with the end of the platinum wire flush with the end of the glass tube have been found to yield good results in marine sediments saturated with water. Defective seals or cracks in the glass tubing, which permit a direct ionic contact of the mercury with the redox system, may cause erratic results.

Each electrode should be carefully inspected and tested in a standard redox system before being used for measuring the E_h of unknown redox systems. A solution of M/300 K₂Fe(Cn)₆ and M/300 K₄Fe(Cn)₆ in M/10 KCl, which has an E_h value of +0.430 volt at 25°C., constitutes a stable, readily prepared standard redox system. Michaelis (1930) recommended as a standard redox system a solution containing 4.000 grams of NaOH and 12.006 grams of acetic acid per liter of distilled water. When a stream of hydrogen is bubbled through this solution to provide for its saturation with hydrogen, such an acetate-hydrogen electrode has an E_h value of -0.273 volt at 25° C.

We have fabricated platinum electrodes in dozen lots which give potential reading which agree within ± 0.001 volt in standard redox systems. Dozen lots of calomel electrodes prepared with an asbestos fiber leak have been found to agree within ± 0.002 volt. This is regarded as satisfactory since the experimental error involved in collecting and treating duplicate samples of sedimentary materials often exceeds 0.01 volt.

Unattackable electrodes made of solid gold wire have been found to be just as good as platinum except that gold wire is more susceptible to breakage from handling. Some workers have advocated the use of gold-plated metal electrodes.

If perfectly plated, such electrodes give satisfactory results, but the slightest imperfection in the plating causes erratic potentials. Unattackable electrodes prepared of special Acheson graphite, as recommended by Tuttle and Huddleson (1934), are simpler to prepare than platinum electrodes, they come to equilibrium faster, and they yield somewhat more reproducible results provided they were used only once. The improved accuracy, however, does not warrant the increased expense and work of preparing new graphite electrodes for each sample of sediment. The graphite electrodes seem to adsorb poising substances from which they can not be readily freed. There is less tendency for poising substances to adhere to platinum electrodes. The latter can be rejuvenated by immersing in hot concentrated nitric acid, rinsing in water, and flaming in an alcohol burner.

An electron-valve potentiometer tends to minimize errors due to polarization. Such an instrument reading to the nearest millivolt is adequate for measuring the redox potentials of sediment samples or biological systems. In earlier work a vacuum-tube potentiometer was used, designed after the one described by Allyn and Baldwin (1932), but in recent years the writer has been using a portable Beckman meter, model G. This instrument provides for direct pH determinations with a glass electrode or for e.m.f. readings with a platinum electrode. By adding the correction factor for the calomel half-cell, the e.m.f. readings can be converted into E_h . The Fisher electrometric titrimeter is especially useful for determining the redox capacity of sediments at different E_h values.

ESTIMATING REDUCING CAPACITY

There are several ways in which the reducing capacity of unconsolidated sedimentary materials can be estimated electrometrically employing the electrodes and potentiometer described in the preceding section. One of the simplest methods is to add a mildly oxidizing agent until the E_h is increased to a certain value, such value to be somewhat below the E_h value of the oxidizing agent. This method is much like the method previously described in which colorimetric indicators are employed for determining reducing capacity, except that the end point is determined electrometrically. The electrometric determination of the end point provides for increased accuracy, makes it possible to work with turbid or highly colored materials, and allows for a greater selection of oxidizing agents.

Unfortunately no one oxidizing agent is entirely satisfactory for estimating the reducing capacity of sedimentary materials. The ideal oxidizing agent would be one which has a relatively high E_h , yet not oxidizing enough to decompose organic matter. This rules out such reagents as hydrogen peroxide, alkaline permanganate, chromic acid and bromine water, for example. The ideal oxidizing agent should be so mild in action that it affects only reversible O/R systems. Moreover, it should not be precipitated by or otherwise react with the constituents of the O/R system. The dyes listed in Table III are about the best oxidizing agents available for this purpose. Slightly acidic (pH 6.5) ferric chloride

solution has been extensively used to estimate the reducing capacity of marine sediments.

A dilute solution of dichromate has also been used for estimating the reducing capacity of bottom deposits and soil. In the method perfected by Sturgis (1936), a 25-gram sample of moist soil is treated with 25 ml. of 0.1 N potassium dichromate and 100 ml. of 0.5 N potassium sulphate in an Erlenmeyer flask. The flask is stoppered immediately and the mixture thoroughly shaken, after which it is allowed to stand for two hours. The solution is filtered off and a 25-ml. aliquot is back-titrated iodimetrically. After adding the potassium iodide, it was found necessary to titrate with the standard thiosulphate solution within five minutes. From the results the "reducing capacity" of the soil was calculated. The procedure, like others which depend upon the use of an oxidizing agent, is open to the criticism that some of the reduced organic compounds in the soil or sediment would not be oxidized and the less soluble reducing inorganic substances would not be affected by the oxidizing agent. Sturgis (1936) concluded, however, that the relative high values obtained and the ease with which duplicates can be checked recommend the method for a comparative study of soils.

The aforementioned method merely tells how much of the oxidizing agent is required to bring the E_h value of the sample up to a certain value or end-point. In characterizing marine sediments it is often desirable to know what the reducing capacity is at different E_h values. Such information can be gained by noting the amount of oxidizing agent required to bring the E_h up to various values. In other words, the sample is titrated stepwise with the oxidizing agent, the E_h end-point being determined electrometrically.

Since atmospheric oxygen influences the state of oxidation or reduction of sedimentary materials, it is necessary to use a closed system. In practice ten grams of mud are weighed into a tared, wide-mouthed bottle similar to the one illustrated in Figure 2. The mud sample is transferred to the bottle with a cork borer fitted with a plunger for expelling the sample. This minimizes the possibilities of oxygen coming into contact with the mud sample. Prior to introducing the mud sample into the bottle, the latter is filled with recently boiled (to exclude oxygen) water cooled to 25°C. The mud sample is broken up with a glass rod to facilitate its dispersion in the water. Now the bottle containing the mud sample and boiled water is stoppered with a large four-hole rubber stopper fitted with electrodes as illustrated in Figure 2 plus two additional small-bore tubes to provide for the introduction of the oxidizing agent and the escape of the liquid which is thereby displaced. The bottle is agitated until the mud is dispersed throughout the water. (Having some large glass beads or marbles in the bottle promotes the agitation of the mud.) Then after determining the E_h of the mud sample, a measured quantity of ferric chloride of known normality is introduced with a pipette having a long capillary tip or with a hypodermic syringe and needle (see Senn, 1945). The bottle is again shaken to mix the contents, and after allowing a few minutes for equilibrium to be approached, the E_h is measured again. This procedure is repeated until no further change is produced by the addition of ferric chloride. The corrected results show the quantity of oxidizable (by ferric chloride in this case) material in the mud sample at different E_h values ranging from the initial E_h of the mud sample to the E_h of ferric chloride. As many points throughout this range of E_h can be obtained as desired by adjusting carefully the amount of oxidizing agent added.

Figure 4 shows the poising capacity of three different samples each having exactly the same initial E_h or reducing intensity and each having the same poise

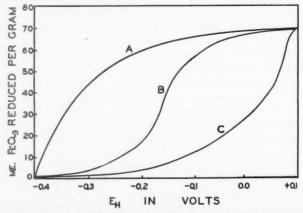


Fig. 4.—Milli-equivalents (M.E.) of ferric chloride reduced per gram of mud at different E_h values. All three samples have same reducing capacity but sample A has high concentration of reductants having low E_0 (-0.4 to -0.2 volt), most reductants in sample B have E_0 of about -0.2 volt, and sample C has high concentration of reductants having relatively high E_0 (o to +0.1 volt).

or reducing capacity at an E_h value of + o.1 volt. However, the stepwise titration of the samples with a mild oxidizing agent shows a difference of large magnitude in the reducing characteristics of the samples. Curve A represents a sample having a high reducing capacity at a low E_h or a sample in which there is a high concentration of reductants having a low E_0 . The opposite condition occurs in the sample represented by Curve C. Curve B depicts a sample in which there is a high concentration of reductants having an E_0 of about -o.2 volt. All gradations of the distribution and concentration of reductants of different E_0 values may be found in samples of recent marine sediments.

REPRODUCIBILITY OF Eh MEASUREMENTS

Employing an electron-valve potentiometer and suitable electrodes, E_h readings on a simple well poised O/R system are reproducible to the nearest millivolt. No such degree of precision is possible, however, with complex and poorly poised systems such as marine mud, soil, and biological materials. O/R conditions in ma-

rine mud samples are in a constant state of flux, resulting in a continuous drift in the E_h readings. When the measurements are made in a closed system from which oxygen is excluded, the E_h drift is generally towards the negative side, or conditions appear to be becoming more reducing in the mud with time. While the E_h of the samples may actually be fluctuating to a certain extent, most of the change observed during the first few minutes after the insertion of the electrodes is an electrode equilibrium phenomenon. It requires from five to ten minutes for equilibrium to be approached, absolute equilibrium never being reached in material like mud or soil which contains living organisms or enzymes. This is illustrated

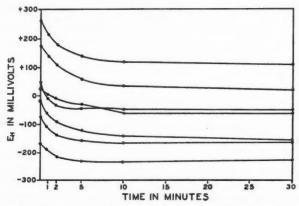


Fig. 5.—Curves depicting change with time in E_h values of seven different mud samples. Rapid negative drift in potential for first few minutes after inserting electrodes in mud sample.

by the data in Figure 5, which shows the E_h values of mud samples read after different periods of time. The average change per minute in the E_h readings during different intervals was as follows.

Time interval	1st min.	2nd min.	2nd to	5th to	10th to
			5th min.	10th min.	30th min.
Change per minute	42 mv.	26 mv.	o my.	2.4 mv.	0.45 mv.

The foregoing data are based upon the average results obtained from making E_h readings on 32 different mud samples after different periods of time.

Peech and Batjer (1935) found that stable E_h readings could be obtained on soils after the electrodes had been in place for 3 or 4 minutes. By using thoroughly cleaned electrodes and salt bridges well flushed with KCl solution, Burrows and Cordon (1936) experienced little difficulty in obtaining stable E_h readings on soil samples, but they report that the problem of fluctuating E_h readings arose in the measurement of potentials of muds from the sea floor. The type of combined calomel half-cell and KCl bridge used in the present work is easily cleaned and has a small but continuous leak of KCl solution.

When two or more pairs of electrodes, which check to within an E_h value of ± 0.002 volt in a simple well poised O/R system, are inserted side by side in a mud sample, the initial E_h readings often differ by as much as 0.02 to 0.05 volt from each other. The divergence decreases with time, but even after 30 minutes the E_h readings obtained with two pairs of electrodes side by side in a mud sample may differ from each other by as much as 0.01 to 0.02 volt. This is partly because the O/R conditions are not uniform throughout the mud and partly because of the inherent technical difficulties of getting reproducible E_h readings on poorly poised materials. The greater the reducing capacity of the material, the more readily reproducible E_h readings can be obtained.

By thoroughly mixing soil with the least quantity of water required to saturate it and then centrifuging the mixture to insure intimate contact of water with soil particles, Brown (1934) electrometrically obtained redox potential readings which he regarded as comparative and reproducible, the deviation of the mean being not more than 0.003 volt. In Brown's method the soil suspension and platnium electrode were left in contact for 30 minutes before taking the E_h reading. There was virtually no difference in the E_h readings taken between 10 and 120 minutes after contact, but on further standing there was a negative drift in potential which increased exponentially with time, and which was attributed to increased bacterial activity in the moistened soil.

The constancy and reproducibility of the redox potential of soils was believed by Herzner (1930) to be dependent on the surface of platinum electrode exposed to the soil, the moisture content, and the time. Herzner recommended saturating the soil with water and making the measurement within an hour after collecting the sample.

He, too, noted that increased bacterial and enzymatic activity caused a negative drift in the redox potential, particularly after saturating the soil with water.

Clark (1925) ascribed the continuous drift in the redox potential of materials containing organisms or their metabolic products to the biochemical activities of partially cytolyzed cells and to the fact that in such systems poising is slow and the processes of oxidation-reduction may not be reversible. As pointed out by Hewitt (1936), the greatest difficulty in dealing with material containing biological systems generally and bacteria in particular is that we do not have rigidly defined static systems of fixed characteristics but constantly changing systems forever in a state of flux. It is only with reservations that the standard formulas for oxidation-reduction equilibrium can be considered as applicable to systems in soils or bottom deposits.

Our attempts to find a satisfactory means of inactivating microorganisms and enzymes whose biochemical activities cause a drift in the E_h of samples of bottom deposits have been discouraging, since chemical or physical agents which inactivate enzymes also destroy certain oxidants and reductants. Constant and reproducible results are obtainable on samples which have been heated to 100°C. for an hour, but the redox potentials of sediment samples thus treated are far dif-

ferent from the values of the original unheated sample. This can likewise be said of samples treated with enzyme-inactivating chemicals.

Thoroughly mixing marine bottom deposits with water in a closed system facilitates the reproducibility of results with a minimum surface of exposed platinum electrode, probably because mixing makes for more uniform O/R conditions throughout the sample. However, if free oxygen comes into contact with the sample, E_h values become more positive. Water itself may cause a change in E_h due to its effect on the solubility, dissociation, and chemical reactivity of constituents.

EFFECT OF DILUTING MUD WITH WATER

Bottom deposits from the sea floor generally contain enough water (40 to 99 per cent) and are of such a physical consistency that the E_h and pH can be deter-

TABLE V

 E_h and pH of Samples of Marine Mud Before and After Being Diluted 1–5 with Boiled Distilled Water. The pH was Determined Electrometrically with a Glass Electrode and the E_h (Corrected to pH 7.0) Was Determined with a Platinum Electrode in a Closed System at 25° C.

Sample	p.	pH of		Eh (in Volts at pH 7.0) of		
No.	Mud only	Mud+Water	Mud only	Mud+Wate		
16-70	7.06	8.84	-0.034	-0.050		
16-71	6.91	8.66	-0.037	-0.054		
16-73	7.38	8.48	-0.142	-0.119		
16-74	7.51	8.64	-o.178	-0.152		
16-75	6.80	8.89	-0.018	-0.018		
16-96	7.32	8.18	-0.306	-0.267		
16-97	7.46	8.63	-0.042	-0.119		
16-115	7.41	8.42	-0.141	-0.086		
16-116	6.79	8.56	-0.115	-0.002		
16-167	6.98	8.70	-0.264	-0.291		
16-168	7.25	8.37	-0.138	-0.068		

mined by inserting an appropriate trio of electrodes (platinum, glass, and calomel half-cell) in a recently collected sample and making potentiometric readings. All-geier et al. (1941) have described a trio of immersion electrodes which can be low-ered to the bottom of lakes for the determination of E_h and pH of bottom deposits simultaneously in situ. Sometimes, though, it is desirable to dilute samples of sedimentary materials with water when estimating their O/R properties. Titrating a sample with an oxidizing agent, for example, entails the dilution of the sample. The effect of such dilution on the E_h may be great or small depending upon the redox capacity or poise of the material, its buffer capacity (because the E_h is influenced by the pH), and several other related factors.

The pH of mud samples is generally affected much more by dilution with water than the E_h , provided free oxygen is excluded. This is illustrated by the data in Table V which gives the pH of several mud samples before and after dilution with five volumes of water. The E_h of the samples is also given corrected to pH 7.0 (by assuming that the E_h becomes more negative by 0.06 volt per unit pH

increase). The mud samples were collected from the Gulf of California. Recently boiled (to exclude dissolved oxygen) distilled water having a reaction of pH 6.30 was used as the diluent. The water was too poorly poised to get reproducible E_h readings on it.

With some samples the addition of water caused an increase in the E_h and with some samples it caused a decrease. With few exceptions the effect on the E_h of diluting mud samples with water was little greater than the range of experimental error in making such determinations after correcting for pH. It made little difference whether the mud was diluted with 1, 2, 5, or 10 volumes of water. However, the pH of mud samples was increased appreciably by diluting them with distilled water. Burrows and Cordon (1936) relate that the effect of moisture content on the redox potentials developed in standing soils is negligible.

Huberty and Haas (1940) observed that dilution of soil samples with distilled water generally resulted in an increase in pH, although with certain poorly buffered samples a slight decrease in pH with dilution was observed. In calcareous soils in which the calcium carbonate-bicarbonate buffer system determines the pH, Huberty and Haas observed an increase in pH of as much as 2pH units when diluted 1–10 with distilled water. Puri and Asghar (1938) pointed out that the pH value of soil is considered to be the result of ionization at the surface of the colloidal particles and hydrolysis of the exchangeable base. The pH of the soil will be changed, then, to the extent that ionization and hydrolysis are affected by the addition of water.

According to McGeorge (1938), diluting soil with water increases the pH of soils until a soil-water ratio of 1-10 is reached, this ratio representing the maximum potential pH of the soil. Kelley and Brown (1921) found that the pH of soil increased with dilution until a maximum was reached at a soil-water ratio ranging from 1-10 to 1-40. We have found the maximum pH of marine mud is generally obtained when the mud is diluted 1-2 to 1-5 with distilled water. Diluting mud with sea water tends to change the pH of the resulting mixture toward pH 8, since sea water is well buffered at around pH 8. The pH of sea water collected from different parts of the ocean ranges from 7.5 to 8.3. The salinity of water from the open ocean ranges from 30 to 40 per cent (see Sverdrup et al., 1942).

Depending on how the measurements are made, it may be necessary to correct the pH of sea water or concentrated brines for salinity, but the concentration of neutral salts such as sodium chloride has very little effect on the E_h . Only to the extent that the concentration of neutral salts may effect the ionization, catalysis, equilibrium, or nature of O/R reactants does salinity influence the E_h of sedimentary materials. The addition of sodium chloride to samples of sedimentary materials in concentrations ranging from 3 to 30 per cent induced changes in the E_h of only 10 to 20 millivolts after correcting for pH, or little more than could be accounted for upon a basis of experimental error. Stuart and James (1938) made similar observations on the effect of sodium chloride on the E_h of protogenous media.

REDUCING CONDITIONS AND CONSTITUENTS IN RECENT SEDIMENTS

 E_h and pH determinations have been made on over a thousand samples of recent marine sediments collected from the sea floor along the coast of California and Lower California during the last 10 years. Most of the samples were collected with a coring device similar to the one described by Emery and Dietz (1941). The E_h and pH determinations were made as soon as possible (generally less than $\frac{1}{2}$ hour) after taking the samples, and all due precautions were exercised to exclude oxygen. The E_h and pH determinations were made electrometrically, the readings being taken after the electrodes had been in contact with the sedimentary material for 5 to 10 minutes. With many samples the electrodes were inserted directly into the freshly collected core. With others, mud from the desired strata was transferred to a squat, wide-mouthed, rubber-stoppered bottle similar to he one illustrated in Figure 2. The E_h measurements were made at the stated pH and at around 25° C. It is believed that the E_h values are correct or reproducible to ± 0.05 volt; the pH values are correct to the nearest 0.1.

The pH of the bottom deposits ranged from 6.4 to 9.5, most of them falling in the range of pH 7.5 to 9.0. Each type of sediment seemed to have its own characteristic E_h and pH. For example, the topmost layers of laminated diatomaceous muds from the Gulf of California showed values of around pH 7.6 and an E_h of about -0.20 volt; the pH of the deeper layers being around 7.9 and the E_h around -0.35 volt. The pH of gray clay from this region ranged from 8.0 to 9.5 and the E_h ranged from -0.05 to -0.15 volt. Sandy bottom deposits collected from shallow well oxygenated water along the coast had redox potentials of E_h +0.150 to +0.350 volt and a pH of 8.0 to 8.3. No constant relationships were noted between the E_h and pH of marine sediments except in so far as the E_h is influenced by the pH.

The pH of most sediments was found to increase with depth. The E_h generally decreases with depth, or conditions were found to be more reducing with depth. These profile variations were greatest within the topmost few inches of the cores. A representative profile series in a laminated diatomaceous mud rich in organic matter is given in Table VI.

Highly reducing conditions were generally found in sediments rich in organic matter. The redox capacity also was generally greatest in sediments containing the most organic matter. The reducing conditions are attributed partly to the presence of hydrogen sulfide which results from the bacterial decomposition of sulpho-proteins or the reduction of sulphates. Ferrous iron is also an important reducing constituent of many sediments. Organic matter appears, though, to be the most important reducing constituent of sediments. Besides contributing to the formation of hydrogen sulphide and reduced iron as a result of bacterial activity in an anaerobic environment, organic matter itself may become reducing.

According to Burrows and Cordon (1936),

the type of decomposable organic matter present in soil is a highly important factor in the determination of the degree of reducing intensity that will prevail.

Willis (1934) lists iron as being one of the reductive constituents of soil, but he regards the activity of soil organic matter as being the most important factor in determining the redox potential. According to Willis, it is debatable whether the reductively active fraction of organic matter is some non-vital by-product of bacterial growth or the organisms themselves. At all events the reducing conditions are directly attributable to the activity of bacteria and allied microorganisms on organic matter. Willis (1934) concluded that a soil subject to depletion of oxygen will develop abnormally low potentials when given any treatment that will stimulate the activity of microorganisms. Shibuya et al. (1936) observed that in waterlogged sandstone-shale soils the redox potential is a function of bacterial

TABLE VI E_h and pH of Mud at Different Depths in a Core of Laminated Diatomaceous Mud Collected from the Gulf of California as Determined Electrometrically at Approximately 2 ς °C.

Core Depth in Inches	pH of Mud	E_h in Volts of Mud at Recorded pH	En in Volts of Mud at pH 7.0
o to 2	7.5	-0.140	-0.110
2 to 4	7.5	-0.193	-0.163
4 to 6	7.7	-0.256	-0.214
6 to 8	7.6	-0.281	-0.245
8 to 10	7.8	-0.315	-0.267
14 to 16	7.7	-0.332	-0.200
18 to 20	7.8	-0.328	-0.280
24 to 26	7.0	-0.338	-0.284
28 to 30	7.0	-0.342	-o.288

activity on organic matter, but the poising system is largely inorganic material, probably reduced iron and manganese.

Kohnke (1934) found the redox potentials of soils to be closely related to aeration and organic content. In the absence of free oxygen, soils in which bacteria are growing rapidly become reducing. Organic matter supplied the bulk of the reducing materials in most of the soils studied by Kohnke. In experiments conducted by Sturgis (1936), the addition of 0.5 per cent utilizable organic matter to certain soils caused them to become more reducing to the extent of about 0.5 volt in 10 days.

The colloidal content of soil, much of which is probably complex organic matter, was found by Keaton and Kardos (1940) to have a distinct bearing on the potential of the soil, but varies for each soil, depending upon the nature and percentage of the colloidal complex and the nature of the soil as a whole. The greater the colloidal content of soil, the lower is the redox potential and the smaller is the percentage oxidation. The extracted colloids of the two soils studied by Keaton and Kardos possessed a lower redox potential than the original unextracted soils. According to these workers, the redox potential in soils is independent of any individual oxidant or reductant, and can be considered as following the ideal equa-

tion only when the concentration of oxidant and reductant is regarded to be the sum of the concentrations of all oxidizing and reducing components in the soil.

Allgeier et al. (1941), who found that lake bottoms are extremely reducing as compared with the overlying oxygenated water, recognized that the complex remains of decomposing plant and animal material play an important role in the creation of reducing conditions. Ferrous iron and hydrogen sulphide were also found to contribute to reducing conditions. Dissolved oxygen is the chief factor responsible for oxidizing conditions. The studies of Allgeier et al. indicated that the redox potentials in lakes are controlled by dynamic factors which are in a state of flux and not by static agents. The implication is that heterotrophic microorganisms which utilize organic matter are the activating dynamic agents.

The effect of free oxygen has been emphasized by Pearsall and Mortimer (1939), who point out the fact that relatively low concentrations of dissolved oxygen suffice to maintain predominantly oxidizing conditions in waterlogged soils. They stress the parts played by ferrous iron, hydrogen sulphide, and certain nitrogen compounds in reduction phenomena.

No definite relationship was found by Sturgis (1936) between the amount of soluble iron and manganese and the total reducing capacity or intensity of soil from rice swamps. Waterlogging the soil, which excludes atmospheric oxygen, caused the E_\hbar to become more negative by about 0.2 volt in the absence of active organic matter and about 0.6 volt in the presence of active organic matter.

After observing redox potentials in oxygenated lake waters ranging from E_h +0.50 volt at the surface to +0.10 volt in hypolimnetic waters relatively rich in ferrous iron, Hutchinson et al. (1939) concluded that ferrous iron is an important poising system. Bacterial activity, however, is probably responsible for the reduced condition of the iron. Both iron and manganese influence the E_h of marine sediments, according to Brujevicz (1937). The presence of an abundance of iron, however, does not necessarily indicate reducing conditions because the iron merely functions as a poising system. In the well aerated, brown, oxidized sediments, rich in iron and manganese, on the floor of the Barents Sea and Kara Sea, which Brujevicz (1938) investigated, the redox potential ranged from E_h +0.105 to 0.250 volt. The pH ranged from 6.7 to 8.3.

Bottom deposits from Lake Glubokoje and nine other Russian lakes near Moscow were found by Kusnetzow (1935a) to have redox potentials ranging from $E_h - 0.142$ to + 0.145 volt. The E_h was found to be more closely related to the oxygen regimen of lakes, organic content, and the abundance of microorganisms than to any other factors. Dissolved oxygen was found by Kusnetzow (1935b) to be chiefly responsible for oxidizing conditions. Bacterial activity on organic matter was believed to be the principal factor in consuming oxygen and creating reducing conditions.

According to the extensive literature reviewed by Hewitt (1936), the tendency of actively metabolizing heterotrophic bacteria and allied microorganisms is to lower the E_h of the medium in which they are growing. Aerobes are easily able to

reduce the medium from an initial E_h value of +0.3 volt to about -0.2 volt or lower. Anaerobic bacteria reduce the medium from near 0.0 to an E_h value of -0.4 volt or lower. A good many bacteria have been described which produce hydrogen overvoltages or which reduce the medium to E_h values more negative than -0.421 volt at pH 7 and 30°C. We have observed an enrichment culture of marine bacteria which lowered the redox potential of a mud sample enriched with peptone from an initial E_h value of +0.264 volt to -0.528 volt at pH 7 and 30°C. Cohen (1931) described experiments designed to show the reducing intensity and capacity of bacteria in which bacteria produced hydrogen overvoltages, and by poising the media with benzoquinone to maintain a readily reversible O/R system, the bacteria produced an electrical current of about 0.2 milliampere at 0.5 volt.

Sulphate-reducing bacteria were found by Aleshina (1938) to cause the O/R of media to drop from an initial E_h value of near zero to as low as -0.340 volt. Both pyrites and calcium polysulphides produced during the reduction of sulphates tended to create reducing conditions.

DISCUSSION

These studies, which are more exploratory than intensive or extensive in nature, indicate that with proper precautions it is possible to estimate the redox potential of recent marine sediments with sufficient precision to be of descriptive significance in characterizing and studying sediments. The range of redox potentials found in sediments is far greater than the range of experimental error in estimating the potentials. Redox potentials ranging from $E_h + 0.350$ to -0.500 volt have been observed in bottom deposits, homologous samples of which give E_h values that are reproducible to within ± 0.01 to 0.05 volt.

One of the most disconcerting features of redox potential measurements of recent marine sediments is that the redox potential of such material is a dynamic property which is in a state of constant flux. The E_h of poorly poised sedimentary materials changes rapidly and appreciably with oxygen tension, bacterial activity, dilution with water, temperature, and other factors. Bacterial or enzymatic activity appears to be the most important dynamic factor which affects the redox potential of bottom deposits.

The negative drift in the redox potential of soil samples has been attributed by Heintze (1934) to the organic content. It has been shown by Burrows and Cordon (1936), however, that the drift is primarily a function of bacterial activity and that the potential may be influenced by both the numbers and kinds of bacteria present. Bacterial activity is influenced by the concentration and decomposability of organic matter.

Bacterial activity in marine muds and the attendant changes in E_h are appreciably accelerated by certain changes which occur during the collection of samples. A ten-fold increase in bacterial population was observed by ZoBell (1938) in mud samples stored for 7 days at 4°C., and much greater and more rapid changes

occurred in mud stored at higher temperatures. This is a commentary on the necessity of making E_h measurements on mud samples as soon as possible after their collection in order to obtain values which are representative of O/R conditions in situ.

To date our efforts to find a means of stabilizing the redox potential of sediment samples have been unsuccessful because all of the substances tried for inhibiting bacterial and enzymatic activity have had a direct effect themselves on the redox potential. Volk (1939a) experimented with mercury compounds, copper compounds, toluene, alcohol, heat, and refrigeration as preservatives to prevent a drift in the redox potential of soil samples by bacterial activity from the time the samples were collected until E_h measurements could be made. Cooling the samples to just above the freezing point and excluding atmospheric oxygen by means of nitrogen proved to be the only procedure which was at all satisfactory.

In view of the multiplicity and complexity of the factors which influence the redox potential of sediment samples, it is noteworthy that values characteristic for each type of sediment are obtainable. The results probably would be viewed with considerable skepticism by the physical chemist, though, because of the large experimental errors involved and particularly because the interpretation of redox potentials of sediments is affected by so many unknown factors. Wartenburg (1935), for example, claims that any correlations between redox potentials and soil properties that have been reported are due to special circumstances and to particular methods employed, and are not explainable by the physical chemist on a basis of true theoretical considerations. The purpose of this paper, however, is to point out that while the E_h values obtained for sediment samples are more descriptive than physicochemically exact, such values may prove to be a useful means of characterizing sediments, since so many chemical and biological processes which affect the diagenesis of sediments are influenced by the redox potential. The capacity factor (poise) as well as the intensity factor (E_h) must be taken into consideration in the characterization of sediments.

Since exploratory observations have shown oil-bearing sands and other petroliferous sediments to have a relatively high reducing intensity and a rather low reducing capacity as compared with other sediments, it is believed that these properties may be proved a significant characteristic of source beds of petroleum or producing horizons. This was anticipated by Trask and Patnode (1942), who emphasized the importance of the "reducing power" of sediments in characterizing source beds.

Trask and Hammar (1935) employed 0.4 normal chromic acid to determine the "reducing power" of sediment samples. Chromic acid is a very powerful oxidizing agent, it being even more oxidizing than the theoretical oxygen electrode. Trask and Patnode (1942) point out that the amount of chromic acid reduced is influenced by four factors: (1) the quantity of organic matter in the sediments, (2) the state of oxidation of this organic matter, (3) the presence of oxidizable inorganic substances such as pyrite, and (4) the extent to which the organic matter

can be oxidized by chromic acid under the conditions of the analysis. Therefore chromic acid reduction is not a good criterion of the reducing capacity of sediments. Recognizing this, Trask and Patnode applied the term "reduction number" to the amount of chromic acid reduced by 100 milligrams of sediment under certain standard conditions. Their "reduction number" is probably more closely related to the oxidizable organic content of sediments than to the reducing intensity or redox potential of sediments.

The "oxidation factor" of Trask and Patnode (1942) is a crude index of the state of oxidation of the organic constituents in sediments. They define the "oxidation factor" as the ratio of the organic carbon content to the "reduction number," pointing out that for any given organic content, the greater the state of oxidation of the organic constituents, the less chromic acid can be reduced and the smaller is the "reduction number." The interpretation of the "oxidation factor" with respect to the state of oxidation of the organic substances in the sediments, however, is affected by three factors, according to Trask and Patnode: (1) the oxidizable inorganic constituents of the sediments, (2) the extent of completeness of combustion of the organic matter by chromic acid under the conditions of analysis, and (3) inaccuracies in determining the "oxidation factor." The opinion was expressed that inorganic substances seem to have relatively little influence upon the reduction number in comparison with the effect of the organic components.

From their extensive reconnaissance investigations on the reducing properties of source beds, Trask and Patnode (1942) conclude that determinations of the state of reduction should be made by more refined methods. Colorimetric and especially electrometric methods of measuring redox potentials and redox capacities may be the answer.

Bacteria have a pronounced effect on the E_h of the medium in which they are growing, and in turn the E_h of the medium influences the growth and metabolism of bacteria. It is claimed by many workers that the growth of anaerobic bacteria is determined by the E_h and not by the oxygen tension. It is a commonly reported observation that growth of anaerobes is possible in the presence of air when the E_h is sufficiently low. If the E_h is above the critical point, free oxygen interferes with the oxidation-reduction processes of anaerobes.

Whether the predominating type of bacterial activity is aerobic or anaerobic has a marked effect on the transformation of organic matter and certain inorganic constituents in sediments. Carbon dioxide is the principal product resulting from the aerobic attack of organic matter; anaerobic processes produce hydrogen, hydrogen sulphide, and methane along with lesser quantities of carbon dioxide. As far as is known hydrogen, hydrogen sulphide, and methane are produced only under anaerobic conditions or at a low E_h . The formation of these gases is believed to be associated with petroleum genesis. Moreover, there is accumulating evidence that petroleum hydrocarbons will be produced by bacteria or accumulate

in recent sediments only when the E_h is low. Nearly all kinds of hydrocarbons are susceptible to bacterial oxidation under aerobic conditions, according to ZoBell et al. (1943), but under anaerobic conditions hydrocarbons are attacked very slowly by bacteria or not at all. For purposes of this discussion conditions may be regarded as anaerobic when the redox potential is negative to $E_h - 0.1$ volt.

SUMMARY AND CONCLUSIONS

The redox potential is a quantitative measure of the state of oxidation or reduction of reversible O/R systems. It can be measured in volts and expressed as E_h . The derivation of the term E_h , which is the e.m.f. of a reversible O/R system referred to a standard hydrogen half-cell, is outlined. Reduced to its simplest form

$$E_h = E_0 + \text{o.o3 log } \frac{\text{(Ox.)}}{\text{(Red.)}}$$

where E_0 and 0.03 are constants and (Ox.) and (Red.) are concentrations of the oxidized and reduced forms of the systems. When (Ox.) equals (Red.) or when the system is 50 per cent in the oxidized state and 50 per cent in the reduced state, E_h equals E_0 . Thus E_0 is defined as the E_h of a reversible O/R system which is half reduced. The term E_0 is used to characterize redox potential indicator dyes and other simple O/R systems.

The redox potential or E_h is an expression of the reducing intensity or electron-escaping tendency of a system, which must be distinguished from the reducing capacity or poise of a system. E_h is analogous to pH or temperature while poise is analogous to buffer capacity or calories in H-ion and heat systems respectively.

The pH of a system influences the E_h by creating or destroying ions, by affecting hydration, et cetera. The E_h of a simple system is a linear function of the pH when the dissociation constant of the reactant is small compared with the H-ion concentration, but when the dissociation constant is large in relation to the H-ion concentration the variation of E_h with change in pH is inappreciable. In simple systems, for each unit increase in pH, E_h becomes more negative by 0.06 volt at 30°C. The average E_h/pH slope for marine mud samples investigated is 0.054 to 0.068 over the entire range between pH 3 and 10, but between pH 6 and 8 the E_h/pH slope ranged from 0.081 to 0.117 volt.

The term rH, which has been used in the literature, is an expression designed to include both E_h and pH of simple O/R systems, but since the E_h does not vary in a known and constant manner in complex O/R systems such as bottom deposits, the use of the term rH is discouraged. In order to be of significance the pH at which E_h measurements were made must be specified.

The temperature at which E_h measurements are made likewise must be specified since temperature has a multiple and unpredictable effect on the E_h of sedimentary materials. For example, a mud sample, which gave an E_h reading of

-0.192 volt at 20°C., gave an E_h reading of -0.308 volt at 90°C., while another gave E_h readings of -0.082 and -0.098 volt respectively at 20° and 90°C.

Techniques for estimating the E_h and reducing capacity with indicator dyes are outlined. The E_0 values at different pH's of several different dyes useful for this purpose are given. Redox dyes can be used to give much valuable information regarding the reducing properties of unconsolidated sedimentary materials, but more precise E_h values can be obtained electrometrically. Types of platinum electrodes and calomel reference cells for the electrometric measurement of E_h of sediments are described. Although the apparatus provides for an accuracy of ± 0.002 volt in E_h measurements of simple well poised O/R systems with a thermionic-valve type potentiometer, results on marine mud samples have proved to be reproducible with an accuracy no greater than ± 0.01 to 0.05 volt. It requires 5 to 10 minutes for equilibrium conditions to be approached after inserting the electrodes in mud samples. Absolute equilibrium is never reached because O/R conditions in recent sediments are in a state of constant flux, resulting in a continuous drift in the E_h readings.

Bottom deposits contain enough water to permit direct E_h readings upon inserting the electrodes, but mixing the sample with water makes for more reproducible results. The addition of de-aerated water affects the pH of bottom deposits much more than the E_h . The concentration of neutral salts has little effect

on the E_h of marine bottom deposits.

The E_h of recent marine sediments ranges from +0.350 to -0.500 volt and the pH ranges from 6.4 to 9.5. Each type of sediment appears to have its own characteristic E_h and pH. Bottom deposits rich in organic matter and bacteria are generally reducing. Negative E_h values or reducing conditions are also a property of fine sediments; coarser sediments are generally less reducing. Positive E_h values are found in well oxygenated bottoms. As a very general rule the E_h and redox capacity decrease with core depth; the pH increases. The reducing conditions found in bottom deposits are attributed to the activity of bacteria which oxidize organic matter. Once created, the reducing conditions are maintained by certain organic compounds, ferrous iron, reduced manganese, hydrogen sulphide, and other inorganic constituents in sediments.

It is believed that detailed data on the redox potential of sediments will contribute to an understanding of the morphology, general nature, and diagenesis of sediments. Such data may find their most important application in the study and characterization of source sediments of petroleum.

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MIOCENE CONGLOMERATES OF PUENTE AND SAN JOSE HILLS, CALIFORNIA¹

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ABSTRACT

Most of the conglomerates of the middle Miocene Topanga formation and the upper Miocene Puente formation in the Puente and San Jose Hills are in the form of thick lenses lying close to the present northeast and northwest margins of the hills. The pebbles, cobbles, and boulders are fragments of plutonic, volcanic, and metamorphic rocks, in part identical with types now present in the mountain masses north and east of the hills. Some rocks, abundant in the mountains, have not been found in the conglomerates, and some of the conglomerate rock types are not known to be exposed now in any possible source region. Nevertheless, it seems probable that the basin which included the area of the Puente and San Jose Hills, received débris from the north and east during middle and upper Miocene time and that the transgressing shore line moved slowly inland, crossing the present northeast margin of the hills in early and middle Puente time.

INTRODUCTION

The Puente and San Jose Hills form a triangular upland that rises above the Los Angeles, San Gabriel, and other physiographic basins east and southeast of the city of Los Angeles (Fig. 1). The southern higher part of the upland—the Puente Hills proper—is bounded on the south by the gorge of the Santa Ana

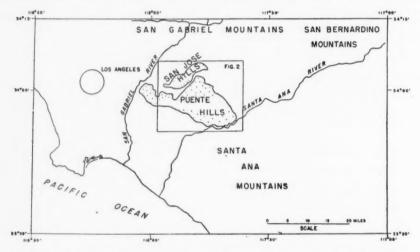


Fig. 1.—Index map of part of southern California, showing Puente and San Jose Hills and area covered by Figure 2.

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³ United States Geological Survey.

River and on the north by the valley of San Jose Creek, a westward-flowing tributary of the San Gabriel River. The San Jose Hills lie north of San Jose Creek. San Juan Hill, the highest point in the upland, is located near the Santa Ana River and has an altitude of 1,777 feet.

This report on the Miocene conglomerates of the Puente and San Jose Hills is based chiefly on a study of about 900 pebbles from 16 localities. The work was done between September, 1943, and July, 1945, in connection with the United States Geological Survey's program of oil and gas investigations. The correlations are based on foraminiferal zoning by M. N. Bramlette and fish-scale zoning by L. R. David. R. M. Alf, of Webb School of California, and R. T. Bean, of the U. S. Forest Service, furnished information concerning the rocks of the San Gabriel Mountains. Many organizations and individuals generously contributed data and aided in other ways. The geologic map (Fig. 2) is adapted, in part, from unpublished surveys by M. L. Krueger and Robert Kelly in the southeastern Puente Hills, by M. L. Krueger and Richard Ten Eyck in the southwestern Puente Hills, and by Bert Mull in the northeastern San Jose Hills.

STRATIGRAPHY

The sedimentary and volcanic rocks that crop out in the Puente and San Jose Hills are of Tertiary age, mostly Miocene and Pliocene. They lie on a pre-Upper Cretaceous complex made up chiefly of granitic and gneissic rocks. The Miocene and Pliocene strata are shales, siltstones, sandstones, and conglomerates, poorly consolidated, variable in thickness, and grading vertically and laterally from very coarse- to very fine-grained, or even to organic, sediments. Foraminifera and fish scales are fairly numerous, and diatoms are locally abundant, but larger fossils are extremely rare. The sediments and volcanic rocks belong chiefly to the middle Miocene Topanga formation, the upper Miocene Puente formation, and the Pliocene Repetto formation.

Basement complex.—The basement complex, as exposed north and south of Pomona (Fig. 2), is made up chiefly of more or less gneissic quartz diorite and granodiorite. Granite has been found in one well, Stella Kraemer-Backs No. 2, southwest of Chino. The San Gabriel Mountains, a few miles north of the San Jose Hills, are composed almost entirely of basement complex, which is there more varied and includes Miller's San Gabriel gneissic complex of mixed sedimentary and igneous materials of possible pre-Cambrian age (W. J. Miller, 1934).

Topanga formation.—A thick conglomerate cropping out in the core of the Buzzard Peak anticline (Fig. 2, C_{I-2})³ in the San Jose Hills, 5 miles west of Pomona, is designated here the Buzzard Peak conglomerate member of the Topanga formation. The conglomerate is overlain with apparent conformity by either the lower member of the Puente formation, or by a few feet of andesite breccia or

³ The letters and numbers refer to the grid system of Figure 2.

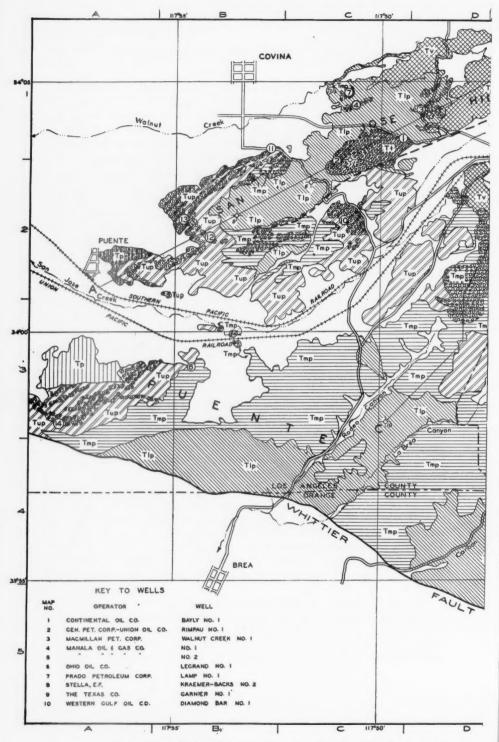
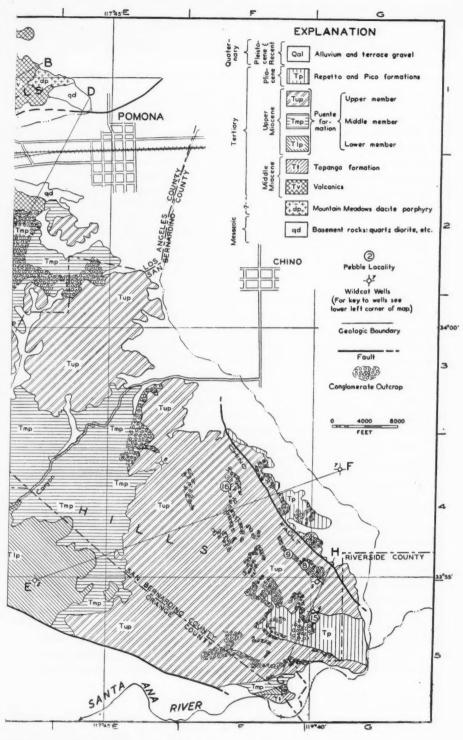


Fig. 2.—Generalized geologic map of Puente and San Jose Hills showing conglomerates,



conglomerate collecting localities, and positions of structure sections.

massive calcic andesite which in turn is overlain by the Puente formation. The outcrop thickness of the Buzzard Peak conglomerate member is about 2,000 feet, but the base is not exposed. The contact of the conglomerate with the underlying volcanic rocks was penetrated in the Continental Oil Company's Bayly well No. 1 at a depth of about 2,300 feet. The maximum known thickness of the con-

glomerate, based on outcrop and subsurface data, is about 3,000 feet.

The Buzzard Peak conglomerate member is made up of sandy conglomerate and coarse-grained pebbly sandstone, with rare silty partings, and west of Buzzard Peak, a few thin beds of white siliceous siltstone. The conglomerate is typically composed of subrounded or subangular pebbles and boulders up to 25 or 30 inches in diameter. The coarse arkosic matrix making up 50 per cent or more of the rock is at least locally, mostly quartz and plagioclase, with some limonitic grains which are probably altered volcanic rock. Cementation is slight at the surface. In the Bayly well No. 1, pebbles and sand grains were coated with discontinuous films of yellow iron sulphide which altered to black powder after a few months' exposure.

The Buzzard Peak conglomerate thins in a short distance westward (Fig. 4, AB). The Ohio Oil Company's Legrand well No. 1, which was drilled only a few hundred feet west of the outcrop area, penetrated about 300 feet of conglomerate and pebbly sandstone, apparently representing only the uppermost part of the outcrop section. The Texas Company's Garnier well No. 1, 1½ miles farther southwest, went directly from shale representing the Luisian and Relizian stages (Kleinpell, 1938) into volcanic rock. Foraminiferal faunas in shale and siltstone cored at depths of 1,733-1,753 and 1,864-1,884 feet in the Legrand well No. 1, 825-950 feet below the top of the conglomerate, indicate Kleinpell's Luisian stage. Ditch samples from 2,560-2,810 feet yielded the *Elphidium granti* faunule which may belong in Kleinpell's Relizian stage. On the northeast the conglomerate is overlain by shales whose abundant microfauna belongs to the lowest part of Kleinpell's Mohnian stage. The Buzzard Peak conglomerate therefore is middle Miocene, and may be correlated with part of the Topanga formation of the Santa Monica Mountains (Hoots, 1930).

Topanga sediments penetrated in wells include the shales and mixed sediments just mentioned, and also notably 2,100 feet of shale, sandstone, and conglomerate in the Western Gulf Oil Company's Diamond Bar well No. 1, near Rodeo Canyon (Fig. 2, C3). These strata in the Diamond Bar well No. 1 are assigned to the Luisian stage on the basis of fish scales.

Volcanic rocks and interbedded sediments of the Topanga are exposed northeast, north, and northwest of the Buzzard Peak conglomerate member, respectively in the northeast tip of the San Jose Hills, in Way Hill at San Dimas, and in the Glendora South Hills, which lie between the San Jose Hills and the San Gabriel Mountains. At Way Hill, a sandstone lens in andesitic volcanic breccia has yielded middle Miocene mollusks and echinoids, and in the Glendora South Hills massive and fragmental andesitic rocks occur in a sequence of sandstones

and siltstones containing Foraminifera and fish scales of Kleinpell's Luisian stage. For these flows and pyroclastics, evidently middle Miocene in age, the term Glendora volcanics is being proposed (Shelton, in press).

Puente formation.—The Puente formation was named from the Puente Hills (Eldridge, 1907, p. 103). It is upper Miocene in age, the equivalent of the upper part of the Monterey shale of many districts. It is made up chiefly of clastic sediments, with minor amounts of interbedded rocks of Monterey facies, such as siliceous siltstone and rarely chert or diatomite. In this report, following the usage of Eldridge, the Puente is divided into three members: a lower member of shale and sandstone, a middle member of sandstone, and an upper member of shale, conglomerate and sandstone. Further subdivision is locally possible, especially in the upper member. The delimitation of the middle sandstone is obviously the key to the three-fold subdivision of the formation. The boundaries of the middle sandstone member cut across time-stratigraphic units, as determined locally both by fossils and by mapping individual beds. The Puente formation has a maximum thickness of possibly 9,000 feet in the Puente Hills, but is much thinner in the San Jose Hills.

The lower member of the Puente formation is mostly clastic, the commonest rock types being dark gray shale, somewhat siliceous pale siltstone, and rather dark gray silty sandstone. North of Brea (Fig. 2, B4), a section measured from a big diabase sill, just north of the Whittier fault, to the middle sandstone member, includes 2,725 feet of sediments, constituted approximately as follows: siltstone and shale 60 per cent, sandstone and pebbly sandstone 30 per cent, limestone 5 per cent, tuff 5 per cent or less. A mile or two northeast, in the Diamond Bar dome, the thickness is 4,000 feet if all of the non-fossiliferous Diamond Bar sand is included in the lower member. Southeast of Carbon Canvon, the member is mostly clay shale, and may be several thousand feet thick. In the San Jose Hills the principal rock is gray to buff shale or siltstone, more or less siliceous, locally containing diatomite, and at the east interbedded with lenses of very coarse conglomerate, the maximum thickness being probably 1,200 or 1,500 feet. The variations from northeast to southwest are shown diagrammatically in Figure 3. The lower member of the Puente belongs to the lower part of Kleinpell's Mohnian stage. The thin section in the San Jose Hills includes both the basal Bolivina modeloensis (or Baggina californica) foraminiferal zone and the overlying Bulimina uvigerinaformis zone. In the Puente Hills, where the section is much thicker, only the Bulimina uvigerina form is fauna has been found, though the lowest few hundred feet of exposed strata and the whole subsurface Diamond Bar sand are barren, and no foraminifera are available from the thick shales of the lower Puente (?) logged in the General Petroleum's Rimpau No. 1 and other wells of the east-central Puente Hills.

The middle sandstone member, buff in color, makes massive outcrops in the Puente Hills. It includes only a few thin beds of clay shale or siltstone. Maximum thicknesses of 2,500 feet or more are attained between Carbon and Brea Canyons

	Lithology, selected Sw and generalized NE		Approx. Max. Thickness	Kleinpell's stage
Pliocene	00000	Pico fm.: shale, siltstone, conglomerate Repetto fm.: micaceous siltstone, conglomerate	(feet) 950+	
		Upper member: shale, siltstone, siliceous siltstone, conglomerate, sandstone. Locally divisible into units of shale-siltstone and conglomerate-sandstone.	2500+	Delmontian and Upper Mohnian
Upper	0000	Middle member: massive sand- stone in central and western Puente Hills; coarse conglomer- ate in northeastern Puente Hills and in San Jose Hills.	2500	Lower
Miocene	0.00	Lower member: shale, siltstone, siliceous siltstone, sandstone, some tuff; thin lenses of coarse conglomerate in northeastern San Jose Hills. Maximum thickness, in Western Gulf Oil Co's Diamond Bar No. I well, may include some sandstone and conglomerate of Topanga fm.	4000	Mohnian
Middle		Topanga formation: sandstone, conglomerate, shale. Chiefly subsurface. Buzzard Peak conglomerate member in central San Jose Hills.	3000	Luisian,
Miocene	And Bs Tribx CoAnd Troan And	Glendora volcanics: chiefly flows and breccias of andesite (And) and calcic andesite (CaAnd), resting on Mountain Meadows dacite porphyry or basement complex. Some basalt(Bs) and dacite or rhyolite. Locally interbedded tuff breccia(tfbx). Sequence variable. Intercalated sediments near top.	3000+	Relizion(?)
Pre- Miocene (?)	4-11-11-11-11-11-11-11-11-11-11-11-11-11	Mountain Meadows decite por- phyry. Dikes and other in- trusive bodies.		
Oligocene(?)	6220000000000000	Sespe(?) formation: brown conglomerate; varicolored sandstone and shale.	600	
Eocene or Cretaceous		Hard gray shale and sandstone.	800	
Mesozoic		Basement complex: chiefly quartz diorite in northeastern Puente Hills; varied plutonite gneisses in San Jose Hill	s.	*

(Fig. 2, D4), and southwest of Puente (Fig. 2, B3). At the latter locality the middle Puente, as mapped, contains much shale in its mid-portion, but has two or three conglomerate beds, aggregating perhaps 75 feet, at the top. Northeastward toward Pomona, the middle Puente becomes conglomeratic throughout, with some giant boulders 12 or 14 feet across, and transgresses on the volcanics of the Topanga (?) formation and the basement complex. North of San Jose Creek, there is no thick extensive body of sandstone in the Puente. On both the north and south flanks of the central San Jose Hills, conglomerates and massive coarse-grained sandstones correlated with the middle Puente are replaced southwestward by thin-bedded fine-grained sandstones and sandy siltstones mapped as upper Puente.

The upper member of the Puente, which is chiefly shale and sandy shale along an east-west axis extending from San Jose Creek to the east margin of the Puente Hills, contains coarser material on the north, northwest, southwest, and far southeast. In the southeastern Puente Hills, between Chino and the Santa Ana River, Max L. Krueger (1943) recognized six subdivisions in the upper member, all of which are exposed along Slaughter Canyon (Fig. 2, F4, where a plane-table traverse gave results summarized as follows.

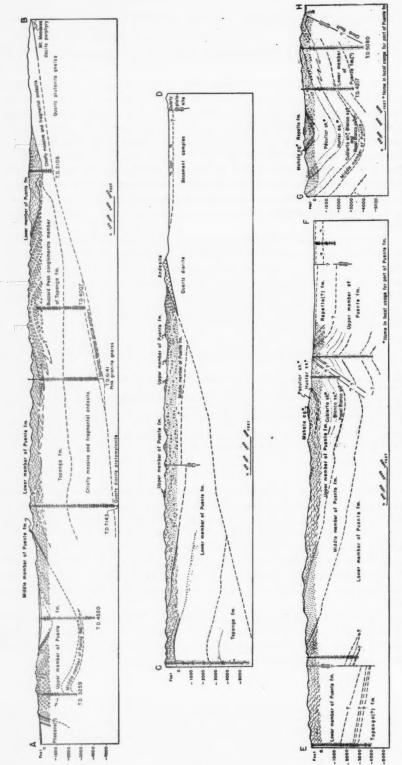
SECTION OF UPPER MEMBER OF PUENTE FORMATION IN SLAUGHTER CANYON

	Thickness (Feet)
Mahala conglomerate, at top: coarse conglomerate with minor sandstone and sandy shale; perhaps in part Pliocene. Peculiar shale: micaceous sandy shale with poor stratification and hackly fracture. Hunter sandstone: sandstone, conglomerate, clay shale. Cubierto shale: thin-bedded gray, micaceous clay shale, fine and medium-grained	30 to 115+ 657 216
sandstoneBlanco sandstone. light-colored, medium- and course-grained sandstonePapel Blanco shale: platy siliceous shale, some chert	864 337 330+
	2,519+

Most of the upper Puente of the southwestern Puente Hills, between Whittier and Puente, was called Pliocene by early workers, because of the presence of thick conglomerates, like those in the overlying Pliocene. Krueger (1936) named the conglomerate-bearing upper Miocene of this area, the Sycamore Canyon formation. The conglomerates shown in the southwest corner of Figure 2 are assigned to his Sycamore Canyon formation by Krueger, and by others. The upper Puente is also conglomeratic in the San Jose Hills, as shown in Figure 2, but thicknesses are much less than in the southwestern and southeastern prongs of the Puente Hills.

The upper Puente belongs almost entirely in the upper part of Kleinpell's Mohnian stage, the *Bolivina hughesi* zone, though south of Pomona it extends down into the *Bulimina uvigerinaformis* zone, and south of Chino, Krueger's Peculiar shale is of Delmontian age (uppermost Miocene).

⁴ Krueger's names.



Fro. 4.—Structure sections through Puente and San Jose Hills. Wells are represented by heavy vertical lines. T.D. = total depth in feet. Two diabase sills are represented by a pattern of crosses in the graphic logs of the two wells near the southwest end of section EF.

Repetto and Pico formations.—The upper Miocene deposits are overlain marginally by Pliocene siltstones, conglomerates, and other sediments assigned on the basis of Foraminifera to the lower Pliocene Repetto and upper Pliocene Pico formations.

VOLCANIC AND SHALLOW INTRUSIVE ROCKS

At the northeast extremity of the San Jose Hills the pale greenish or yellowish Mountain Meadows dacite porphyry intrudes and overlies gneissic bedrock, the principal porphyry mass having an outcrop 5,500 by 2,500 feet. A nearly identical rock was cored in the Ohio Oil Company's Legrand No. 1 between about 5,900 and 6,100 feet, and in the Continental Oil Company's Bayly No. 1 below 3,885 feet. The same or nearly the same rock is very common in the south-central San Gabriel Mountains, especially between San Gabriel and San Antonio canyons.

The Mountain Meadows dacite porphyry is overlain, probably uncomformably, by the Glendora volcanics—a sequence of andesites and other volcanic rocks, probably at least half of which are pyroclastic breccias or tuff breccias. In the northeastern San Jose Hills hypersthene andesite is the commonest rock, but calcic augite andesite, olivine basalt and rhyolite (or dacite) are present. In the near-by northeastern nose of the Puente Hills, volcanic rocks in similar stratigraphic position are mostly sodic andesite (and dacite?) accompanied by a very little calcic andesite. Farther west, in Bayly No. 1, Legrand No. 1, and other wells, and in outcrop northwest of the hills, pale calcic andesite with hypersthene (?) is the principal rock, with unmistakable basalt rarely present. These volcanic rocks are as much as 3,000 feet thick, as shown by the Texas Company's Garnier No. 1 and other records. They are in part, and perhaps entirely, of Topanga (middle Miocene) age (Relizian and Luisian stages) as shown by interbedded foraminiferal fish-bearing and mollusk-bearing siltstones and sandstones in the Glendora South Hills, northwest of San Jose Hills, and elsewhere.

Diabase sills up to several hundred feet in thickness occur near the base of the exposed lower member of the Puente north of Brea. Intrusive diabase and gabbro bodies that appear to be much thicker were penetrated in strata probably of lower Puente age, in the General Petroleum-Union's Rimpau well No. 1, 6 miles southeast of the outcropping diabase. Diabase has also been reported in several other wells, including some that are 2 or 3 miles southeast of the town of Puente.

STRUCTURE

The generalized geologic map (Fig. 2) and the structure sections (Fig. 4) indicate the geologic structure of the area.

Major faults.—The long southwest margin of the Puente Hills is approximately determined by the Whittier fault, although a narrow border of dissected folded sediments lies southwest of the fault zone. The somewhat shorter northeastern edge of the hills is determined in part by the Chino fault. The Indian Hill

fault approaches the northern edge of the hills in the vicinity of San Dimas. Elsewhere the valley mouths of the dissected upland are drowned in Pleistocene or Recent alluvium. Within the hills one important fracture zone, the San Jose fault or faults, follows the north side of San Jose valley northwest of Pomona and continues westward into the San Jose Hills south of their higher and more rugged portions.

Folds.—In the central part of the Puente Hills the beds are slightly deformed, whereas the marginal areas, including the whole of the San Jose Hills, are characterized by relatively sharp folds. The axes of most of the folds are nearly, but not exactly, parallel with the margins of the hills.

Marginal basins.—The broad and varied Los Angeles Basin extends from the Puente Hills to the ocean (Fig. 1). The San Gabriel Basin lies west of the San Jose Hills. The upper Santa Ana Basin or Ontario Plain lies northeast of the area studied. The portion of the upper Santa Ana Basin closest to the Puente Hills is a structural trough, filled with marine sediments and alluvium, and is designated the Chino Basin.

AREAL DISTRIBUTION OF CONGLOMERATES

The region in which the Miocene conglomerates were studied was rather arbitrarily limited to the San Jose Hills and the main Puente Hills, east of the Turnbull Canyon oil fields. The conglomerates in the western prong of the Puente Hills, also called the Whittier Hills, have been described by E. C. Edwards (1934) and G. J. Bellemin (1940). In the area here considered conglomerates are exposed at the surface along the northeastern and northwestern margins of the triangular hill-land. The sizes of the pebbles in general decrease as a given bed or set of beds is traced southwestward or southeastward into the hills.

The Buzzard Peak conglomerate member of the Topanga formation (middle Miocene) is exposed in the core of the Buzzard Peak anticline. It contains many boulders which are more than 2 feet in diameter. Conglomerate in the Topanga, composed of smaller pebbles, rarely more than two or three inches in diameter, was cored in the Western Gulf's Diamond Bar No. 1 (Fig. 2, C3) and probably also in the General Petroleum-Union's Rimpau No. 1 (Fig. 2, D4, 5). Finegrained conglomerate, which may be Topanga in age, has also been found in other wells, between Buzzard Peak and the Diamond Bar well.

The conglomerates of the lower member of the Puente formation are few and thin, but locally contain many boulders 4-8 feet in diameter. They are limited to the northeastern portion of the San Jose Hills and grade southwestward into siltstone and shale.

The middle member of the Puente formation is chiefly conglomerate southwest of Pomona but grades into sandstone before the Diamond Bar well is reached. Similarly in the San Jose Hills, the conglomerate mapped as middle Puente grades southwestward into siltstone and thin sandstone beds. Between

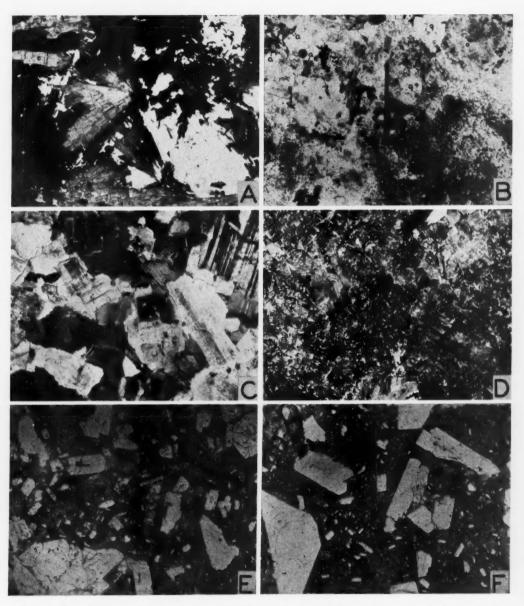


Fig. 5.—Photomicrographs of clasts and source rocks. Magnification, 13×. A. Tourmaline-quartz rock, Cajalco tin mine, Perris block. Ordinary light. Tourmaline gray or black, quartz white. B. AOW 2502A. Tourmaline-actinolite quartz monzonite, boulder in upper member of Puente formation, loc. 10, central San Jose Hills. Ordinary light. Dark tourmaline prism and 3-fold cross section in center; a=actinolite; b=biotite; o=orthoclase; p=plagioclase; q=quartz; s=sphene. C. AOW 2412C. Biotite quartz diorite, 14-foot boulder in middle member of Puente formation, loc. 5 southwest of Pomona. Crossed nicols. D. AOW 2443B5. Albite porphyry, spherulitic, cobble in Krueger's Mahala conglomerate at loc. 16, southeast Puente Hills. Crossed nicols. E. AOW 2605D. Hypersthene(?) andesite, cobble in middle member of Puente formation at loc. 6, west central Puente Hills. Ordinary light. F. AOW 2360A. Hypersthene andesite, Glendora volcanics northwest of Pomona. Ordinary light. Hypersthene dark-bordered; other phenocrysts plagioclase.

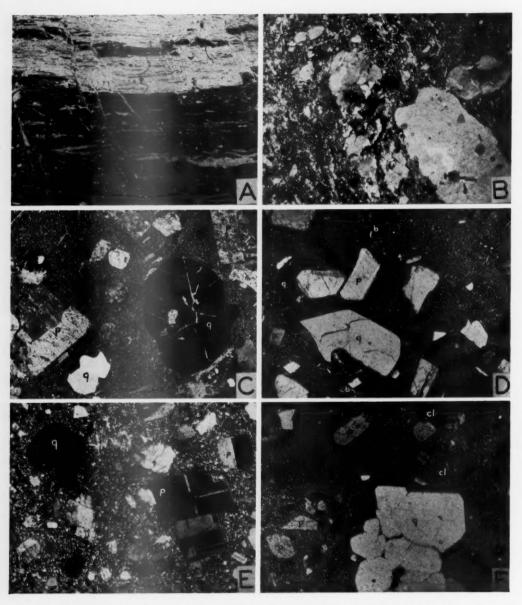


Fig. 6.—Photomicrographs of clasts and source rocks. A. AOW 2511D. Quartz plutonite mylonite, cobble in Buzzard Peak conglomerate member of Topanga formation. Ordinary light. 13×. B. AOW 2556B. Biotite quartz plutonite mylonite gneiss, from conglomerate in lower member of Puente formation, San Jose Hills. Crossed nicols. 11×. Largest grain orthoclase with quartz inclusions. C. Mountain Meadows dacite porphyry, from dike in Stoddard Canyon, San Gabriel Mountains. Crossed nicols. 13×. D. S87. Mountain Meadows dacite porphyry, pebble in middle member of Puente formation, southwest of Pomona. Crossed nicols. 13×. E. AOW 2357B2. Biotite granodiorite porphyry, cobble in Krueger's Mahala conglomerate, southeast Puente Hills. Crossed nicols. 13×. F. AOW 2568B. Mountain Meadows(?) dacite porphyry, cobble in Krueger's Hunter conglomerate at loc. 9, southeast Puente Hills. Crossed nicols. 13×. In C, D, E and F: b=biotite; cl=chlorite; p=plagioclase; q=quartz.

the town of Puente and the Diamond Bar well, a few thin conglomerate beds are present locally at or near the top of the sandstone of the middle Puente.

The conglomerates of the upper member of the Puente formation are concentrated in the San Jose Hills and at the southwestern and southeastern promontories of the Puente Hills. Though thick and extensive, they are not as coarse-grained as the underlying conglomerates. In the southeastern area the conglomerates of the upper Puente are restricted chiefly to the east side of the Ridge syncline and the south side of the Bryant fault. They thin westward and disappear about one mile west of the synclinal axis. In the San Jose Hills, the conglomerates of the upper Puente are coarsest south of Buzzard Peak and perhaps most extensive on the northeastern slope of the hills between Covina and Puente. The uppermost conglomerates of the Puente formation of the southwestern Puente Hills (placed by Krueger in his Sycamore Canyon formation) are several hundred feet thick, very lenticular, and appear to grade into finer sediments toward the southeast.

ROCK NOMENCLATURE

The term clast is used for "clastic fragment."

Coarse-grained igneous rocks from granite to peridotite are called *plutonites*. Igneous rocks with numerous phenocrysts and microcrystalline ground mass are called *porphyries*. They show less flow structure than do the volcanic flow rocks. Porphyries in the conglomerates differ strikingly in texture, but it is difficult to give a rule by which groups may be recognized. An attempt is made to differentiate the granite porphyry group, with even-granular groundmass made up of grains 25 or more microns across, and the rhyolite porphyry group, with groundmass of finer grain or of uneven grain size, including grains below 25 microns. A rock of the rhyolite porphyry group with relatively few phenocrysts and a groundmass of lath-shaped feldspar, called dacite porphyry, may, however, have a coarser groundmass than a phenocryst-packed quartz diorite porphyry with an evengranular groundmass. In attempting to put similar rocks in the same group rules are not rigidly applied.

The quartz-bearing plutonites are subdivided on the basis of the ratio between alkali and soda-lime feldspars, as follows: more than 2:1, granite; between 2:1 and 1:2, quartz monzonite; between 1:2 and 1:19, granodiorite; less than 1:19, quartz diorite.

The term soda granite is used for a rock composed essentially of quartz and albite, with or without potash feldspar, and a similar rule is used for soda rhyolite et cetera.

Where one or more mineral names are used to indicate a rock variety, as in hornblende-biotite quartz diorite, the minerals are arranged in the order of increasing abundance. In the example chosen, quartz diorite is really a primary rock name, and the order of the other two minerals indicates that biotite is the more abundant. The same rule is applied to metamorphic rocks, reversing the previous usage of the senior writer (e.g., Woodford, 1925).

The terms schist and gneiss are strictly textural. In gneiss most bands are 1 millimeter or more thick; in schist most bands are less than 1 millimeter. A paragneiss is a metamorphosed sedimentary rock. Mylonites are considered metamorphic rocks and their definition is discussed in the next section.

ROCK TYPES REPRESENTED IN CONGLOMERATES

Sedimentary rocks are almost completely absent from the conglomerates. Quartz pebbles are extremely rare. The most abundant types are quartz-bearing plutonic rocks, dark-colored volcanic rocks, mylonite, and biotite gneiss. Porphyries are locally prominent.

The common and distinctive rock types found in the conglomerates are de-

scribed under the names used to designate them in the locality lists.

Biotite (and muscovite) granite.—Moderately abundant, but studied microscopically in few cases. Coarse-grained, pale, commonly even-granular but not rarely gneissoid. Composed essentially of quartz and orthoclase (or rarely microcline). Oligoclase commonly almost half as abundant as potash feldspar; some muscovite usually present. Myrmekitic intergrowths present in some specimens.

Biotite (or muscovite) soda granite.—Fairly common in lower Puente, rare in upper Puente. Medium- to very coarse-grained, even-granular, pale rock; composed of quartz, albite, and orthoclase (or microcline) in varying proportions, with small percentages of biotite or muscovite or both; sometimes epidote, chlo-

rite or pyrite as minor accessories. Rarely myrmekitic intergrowths.

Actinolite quartz monzonite, and soda granite.—The most obvious and striking feature of these rocks is the presence of pale green, corrugated, pseudo-micaceous flakes composed of actinolite needles. Tourmaline, where present in the actinolite quartz monzonite, occurs as small blue-black needles, ordinarily sparsely distributed, more rarely amounting to 5 or even 10 per cent of the rock (Fig. 5B); dichroism: o=pale blue, e=gray, colors much paler than ordinary schorl. The abundant minerals are quartz, orthoclase as big pinkish phenocrysts, and albite or oligoclase. Epidote and sphene are almost always present. Rarely there is a little brown biotite, partly altered to chlorite. If the plagioclase is albite, the rock is called soda granite; if it is oligoclase and abundant, the rock is quartz monzonite or even granodiorite. In some specimens albite is spotted with epidote or clinozoisite, suggesting that both minerals formed at the expense of soda-lime feldspar. Widely distributed in the conglomerates, and abundant as large boulders in the upper Puente of the San Jose Hills.

Perris quartz diorite (Dudley, 1936; same as Val Verde tonalite of Osborne, 1939; correlated with Bonsall tonalite of Hurlbut, 1935 and probably with the Wilson diorite of Miller, 1934).—Gneissoid, moderately dark-colored hornblende-biotite quartz diorite and granodiorite. The commonest and most widely distributed plutonic rock of the Perris block and Peninsular Ranges east and southeast of the Puente Hills. This rock, if present at all in the conglomerates, is extremely rare. One pebble of this type was found in a conglomerate of the upper

Puente (Krueger's Sycamore Canyon) near Hacienda Boulevard, and two possible but atypical examples in the conglomerate of the upper Puente designated the Hunter conglomerate by Krueger.

Aplite.—Mostly granite aplite, composed essentially of quartz and orthoclase (or microcline), with soda-lime feldspar less than half the potash feldspar. Commonest accessory muscovite, next commonest biotite, and third pink garnet; rarely epidote or magnetite. In some specimens myrmekite structure is very prominent. A garnet-muscovite soda aplite (albite more abundant than orthoclase plus microcline) was found in Krueger's Mahala conglomerate of uppermost Miocene or Pliocene age. Pebbles of quartz diorite aplite (no alkali feldspar) and grandodiorite aplite (little alkali feldspar) were found in the upper Puente near the west end of the San Jose Hills, but they are much rarer than granite aplite.

Alaskite.—Granitic texture, but with dark minerals almost completely lacking. Typical alaskite, with granite composition, was found in the Buzzard Peak conglomerate member of the Topanga and in the conglomerates of the lower Puente. Albite-rich soda alaskite was found in the middle and upper Puente, and a quartz monzonite "alaskite" (oligoclase and orthoclase approximately equal) in the lower Puente.

Pegnatite.—Common; in general granite-pegnatite, with potassic feldspar more than twice the soda-lime feldspar. Oligoclase or albite-oligoclase is usually present, together with one or more of the following accessory minerals: muscovite, biotite, garnet, epidote.

Mountain Meadows dacite porphyry.—A rock with phenocrysts of euhedral oligoclase and biotite, and less abundant partly resorbed quartz in a rather pale greenish or yellowish gray, ordinarily altered, probably microcrystalline groundmass (Fig. 6D). Phenocrysts are mostly 1 to 4 millimeters maximum diameter. Rarely they include a few altered grains of hornblende. Groundmass contains orthoclase. The local name comes from the largest exposed mass, 2,000 feet across, intrusive into the basement complex at the Mountain Meadows Country Club just northwest of Pomona. The rock also occurs as swarms of dikes and possibly other masses in the San Gabriel Mountains between San Gabriel Canyon and Cucamonga Canyon. Rather widely distributed, but rare, at most of the conglomerate localities studied.

Analysis of Mountain Meadows Dacite Porphyry. Sample somewhat weathered and stained brown on fractures, from depth of 4000 ± feet, the Continental Oil Company's Bayly No. 1, near Buzzard Peak, San Jose Hills.

[M. K. Carro	n, analyst]	
68.75	H ₂ O+	1.79
14.76	K ₂ O	2.74
1.59	Na ₂ O	3.44
.83	BaO	.07
2.22	S	.05
.95	MnO	.18
. 22		
2.06		99.65
	68.75 14.76 1.59 .83 2.22 .95	14.76 K ₂ O

I.(3)4.2(3).(3)4. Lassenose. Niggli numbers: si 348, al 44, fm 18, c 12, alk 26; k .34, mg .41. Close to the original dacite (Tröger No. 148), except for the somewhat higher si.

Temescal Wash dacite porphyry (New name for Temescal dacite porphyry, Dudley, 1936).—Dark-colored rock, with plagioclase and quartz phenocrysts and inconspicuous biotite or hornblende. There is also a phase with numerous phenocrysts and coarser groundmass, which is more properly called quartz diorite porphyry. The dark minerals are anhedral and obscure, in contrast to the black hexagonal biotite plates which are such striking constituents of the pale Mountains Meadows dacite porphyry.

The Temescal Wash dacite porphyry is now exposed over a wide area a few miles southeast of the Puente Hills. An identical or similar rock has been found as a rare constituent of the conglomerates of the upper Puente in the southeastern Puente Hills and at locality ro in the central San Jose Hills. In the conglomerates

this rock is much rarer than the Mountain Meadows dacite porphyry.

Granophyre.—Holocrystalline with micrographic and spherulitic (or pseudospherulitic) textures (cf. Fig. 5D). Mostly orthoclase and quartz.

Soda rhyolite.—Varied, with phenocrysts of albite or quartz, or both, in a finegrained, more or less altered groundmass. Fairly common near Puente, in con-

glomerates of the middle and upper members of the Puente.

Andesite.—Ordinarily porphyritic, with a fine-grained groundmass and some glass. Phenocryst and groundmass feldspar with An less than, or close to, 50 per cent. Where not altered beyond recognition, the dark minerals are more commonly pyroxene than hornblende or biotite. The rock is very abundant in the upper Puente of the San Jose Hills and in the middle Puente southeast of Puente town.

Basalt.—Not certainly identified. Some doubtful examples with labradorite phenocrysts, An about 55 per cent, but with glassy or altered material in the groundmass. Some pebbles may be spilitized basalt or diabase, with albite re-

placing original labradorite.

Mylonite and mylonite gneiss.—Following Lapworth (1885) and Waters and Campbell (1935) "mylonites may be described as microscopic pressure-breccias with fluxion-structure, in which the interstitial dusty, siliceous, and kaolinitic paste has only crystallised in part." Pebbles of cataclastic mylonite are very rare in the Miocene conglomerates, but similar rocks with recrystallized groundmass (here called mylonite gneiss, cf. Fig. 6B) are locally abundant, especially in the Buzzard Peak conglomerate member of the Topanga and in the lower Puente of the northeastern San Jose Hills. The thin sections studied all indicate quartz plutonite compositions, mostly those of granite and quartz monzonite, exceptionally granodiorite and quartz diorite.

A very few examples of cataclastic granitic rocks of arkosic appearance have been found as pebbles. These belong to the group of *protomylonites*.

Most of the mylonitic pebbles contain shredded biotite or fine-grained chlorite.

Biotite-quartz plutonite gneiss.—Commonly too rotten for satisfactory determination of feldspar. In most of the fresh examples orthoclase predominates over plagioclase. At one exceptional upper Puente locality (no. 11) in the north

central San Jose Hills, three examples of biotite quartz diorite gneiss were found, although granite gneiss was lacking.

Biotite-quartz gneiss was found in great variety. All examples are considered paragneisses.

PEBBLE COUNTS AT SELECTED LOCALITIES

Conglomerates of the Topanga and Puente formations, including Krueger's Mahala conglomerate of questionable Puente age, were studied at 16 selected localities. Counts were made at 14 of these localities, in general including all the clasts above 1½ inches in diameter which were exposed in a selected area of outcrop. Representative samples were transported to the laboratory, where they were further studied in thin section or by other methods. About 900 pebbles, cobbles, and boulders were identified, by Woodford.

The pebble localities are arranged in four generally stratigraphic groups: Topanga (Buzzard Peak conglomerate member), lower Puente, middle Puente, and upper Puente. The middle Puente localities 6 and 7 may be very close in geologic age to some of the upper Puente localities, and notably younger than middle Puente locality 5.

The Buzzard Peak conglomerate member of the Topanga formation is well exposed, especially along a summit road following the Buzzard Peak ridge. Only 83 pebbles from two localities are listed, but observations elsewhere indicate that pebble composition is rather uniform throughout the exposures. Rotten ferruginous volcanic boulders, often of large size, are probably somewhat more common than the lists indicate. The feature of the member is the abundance of mylonitic rocks, which are probably more common than the lists show.

Buzzard Peak conglomerate member of Topanga formation, count of pebbles at locality I (Fig. 2, CI), 13,200 feet south and 7,400 feet west of northeast corner of Covina Quadrangle, on the north side of U. S. Highway 70, opposite the W. K. Kellogg gateway and about 50 feet upgrade from it.

Plutonites	No. of Specimens	Per- centage
Biotite granite with considerable plagioclase, most specimens pinkish,		
some porphyritic	7	
Biotite granodiorite, pale, rather rotten	3	
Total plutonites	10	20
Aplite, alaskite, and pegmatite		
Alaskite, with small orthoclase phenocrysts, and a little biotite	6	
Granite aplite	3	
Quartz monzonite aplite	1	
	_	
Total aplite, alaskite, and pegmatite	10	20
Volcanic		
Rotten andesite or basalt. Large (6-8 inch) blocks	2	
Total volcanic	2	4
Metamorphic		
Granite mylonite with dark, chloritic matrix	9	
Mylonite gneiss, in part with numerous eyes, including quartz monzonite	0	
gneiss and granodiorite mylonite gneiss	8	
Biotite-quartz plutonite augen gneiss, rather rotten	4	
Amphibolite, non-schistose	1	
Biotite-quartz paragneiss Quartz with a very little biotite, probably from coarse gneiss	3	
Quartz with a very little biotite, probably from coarse gness	-	
Total metamorphic	27	
rotal metamorphic	2/	54

Vein	No. of Specimens	Per- centage
Vein quartz	1	
	_	
Total vein	I	2
Grand total	50	100

Five specimens from locality 1 were studied under the microscope.

The largest boulders at locality 1 are 25 to 30 inches across. Most are subangular, as shown in Figure 7, a photograph of a portion of the exposure 50-75 feet west of the collecting locality. Coarse sandy matrix makes up at least 50 per cent of the rock.



Fig. 7.—Part of Buzzard Peak conglomerate member of Topanga formation near locality 1 on U. S. Highway 70. Pick rests against largest (20-inch) boulder.

Buzzard Peak conglomerate member of Topanga formation, count of pebbles at locality 2 (Fig. 2, C1, 2), 15,750 feet south and 15,450 feet west of northeast corner of Covina Quadrangle, 250 feet west of Buzzard Peak, on summit road.

Plutonites	No. of Specimens	Per- centage
Biotite granite and quartz monzonite, slightly gneissic	6	
Biotite quartz diorite (dark, 20 per cent biotite)	1	
Total plutonites	7	22
A plite, alaskite, and pegmatite		
Alaskite	2	
Granite aplite	2	
Granite or quartz monzonite pegmatite (some oligoclase and biotite)	3	
Quartz, probably pegmatitic	2	
Total aplite, alaskite, and pegmatite	_	
Total aplice, alaskite, and pegmatite	9	27
Porphyries		
Mountain Meadows dacite porphyry (fresh)	x	
	-	
Total porphyries	1	3

Volcanic	No. of Specimens	Per- centage
Andesite, fine-grained, rotten	4	
Total volcanic	4	12
M etamor phic		
Dark, fine-banded mylonite, rather rotten	3	
Quartz-rich rocks, probably mylonites Quartz monzonite mylonite gneiss	2	
Quartz-feldspar mylonite gneiss with feldspar eyes	2	
Biotite-quartz plutonite gneiss, probably mylonite gneiss	2	
Biotite granite gneiss	I	
Biotite granite gneiss, coarse and dark (25 per cent biotite)	1	
	_	
Total metamorphic	12	36
Grand total	22	100

Five specimens from locality 2 were studied under the microscope.

Half the rock sampled is coarse, sandy matrix, mostly quartz and plagioclase. The largest boulders are mylonites, biotite plutonites, and rotten volcanics 12 to 20 inches across.

The lower half of the Buzzard Peak conglomerate member of the Topanga formation is known through 13 standard cores of the Continental Oil Company's Bayly No. 1, depths 700-2,300 feet. As in surface exposures, the larger clasts are chiefly quartz-rich plutonic rocks and porphyries, mylonites, and gneisses, with calcic andesite rare. The conglomerate is finer grained below a depth of 900 feet, with some coarse sand beds, and with most of the conglomerate beds made up of pebbles less than 2 inches across.

Elsewhere in the area, the best dated conglomerates of Topanga age are those in the 3,200 feet of sediments with Luisian fish scales penetrated by the Western Gulf Oil Company's Diamond Bar No. 1, 6 miles south of Buzzard Peak, between depths of 3,572 and 6,828 feet. Half the section is black or gray calcareous shale, and half is medium- to coarsegrained, arkosic sandstone with gritty and pebbly beds. In three sandstone and grit samples from depths of 4,523, 4,571 and 6,811-16 feet, quartz, andesine, and oligoclase predominate, with considerable orthoclase and some biotite, and microcline and muscovite present. The pebbles available for study include small fragments of coarse, pale quartz diorite or quartz diorite pegmatite, and larger pebbles, up to 3 inches diameter, of biotite quartz gneiss and rotten andesite(?).

Conglomerates of lower member of Puente formation, count of pebbles at locality 3 (Fig. 2, D1), 9,500 feet south and 5,200 feet west of northeast corner of Covina Quadrangle, at top of Hill 1075+, just west of the Puddingstone Lake road.

Plutonites	No. of Specimens	Per- centage
Biotite granite	2	
Biotite granite (?)	2	
Biotite soda granite	1	
Muscovite-biotite granite, coarse	3	
Garnet-muscovite soda granite, with a little biotite	1	
Gneissoid biotite granite	2	
Kataclastic biotite granite	I	
Total plutonites	12	24

Aplite, alaskite, and pegmatite	No. of Specimens	Per-
Granite aplite with a little biotite	8	
White granite pegmatite	2	
Blue-gray granite pegmatite Sheared, pale gray granite pegmatite	. 3	
Sheared, pane gray granite pegmatite	_	
Total aplite, alaskite, and pegmatite	14	28
Porphyries		
Biotite granite porphyry, very pale	1	
Total porphyries	1	2
Volcanic		
None (some rotten volcanics elsewhere in the same bed)		
Metamorphic		
Feldspathic protomylonite	3	
Biotite granite mylonite, partially recrystallized Biotite quartz monzonite and granite mylonite gneiss, with orthoclase and	1	
plagioclase eyes	7	
Quartz-orthoclase mylonite gneiss, perhaps after pegmatite Granite or quartz monzonite mylonite gneiss, fine-grained, gray, with	I	
orthoclase and quartz eyes	2	
Granite (?) mylonite gneiss, very pale, very fine-grained Kataclastic quartzite	I	
Graphite-quartz gneiss, fine-grained, fine-banded	2	
Amphibolite gneiss (more than 50 per cent oligoclase and andesine)	2	
Biotite gneiss (granite gneiss (?))	1	
Quartz gneiss (95 per cent quartz, 5 per cent biotite)	3	
Total metamorphic	22	44
Vein		
Quartz	1	
Total vein	1	2
Grand total	50	100

Seven mylonitic and 5 other specimens from locality 3 were studied under the microscope.

The boulders and cobbles form a residual accumulation along a ridge. There are several 30-inch boulders here, and near at hand others which are 4 or 5 feet across. A similar assemblage to that at locality 3, at about the same horizon, was found a few hundred feet away in a cut bank beside the Puddingstone Lake Road, but the clasts are too rotten for microscopic study.

Conglomerate of lower member of Puente formation, count of pebbles at locality 4 (Fig. 2, C_I), 9,100 feet south and 13,100 feet west of northeast corner of Covina Quadrangle, 150 feet south of summit 1,035.

Plutonites	No. of Specimens	Per- centage
Musovite-biotite granite, gneissoid	2	
Musovite-biotite granite, porphyritic, gneissoid	2	
Biotite granite, pale, gneissoid	1	

		4
	No of Specimens	Per- centage
Biotite granite, porphyritic, very coarse (3-15 mm.)	2	
Biotite granite, porphyritic, gneissoid	2	
Muscovite-biotite soda granite	1	
Muscovite-biotite quartz monzonite, gneissoid, 100-inch boulder	1	
Biotite quartz monzonite, pale, gneissoid, southeast San Gabriels type	1	
Biotite quartz monzonite or granodiorite, fine-grained, southeast San		
Gabriels type	1	
Total plutonites	13	26
A plite, alaskite, and pegmatite		
Muscovite-biotite granite or quartz monzonite aplite	2	
Alaskite	3	
Quartz monzonite "alaskite"	1	
Granite pegmatite	3	
Biotite granite pegmatite, gneissoid	1	
Biotite quartz diorite pegmatite, sheared and recrystallized	1	
m . 1 . 1 . 1 . 1	-	
Total aplite, alaskite and pegmatite	11	22
Porphyries		
Mountain Meadows dacite porphyry	2	
Total porphyries	2	4
Volcanic		
Porphyritic fine-grained andesite of Puddingstone Lake type	4	
Porphyritic fine-grained andesite, red mottled	I	
Total volcanic	5	10
M etamor phic		
Dark gray granite mylonite, small (1-3 mm.) eyes	4	
Dark gray biotite granite mylonite, large eyes	1	
Sheared, weathered feldspathic mylonite	1	
Biotite quartz monzonite mylonite gneiss, large eyes	4	
Biotite granodiorite mylonite gneiss	2	
Garnet quartz diorite pegmatite mylonite gneiss	1	
Biotite granite gneiss	3	
Biotite granite gneiss protomylonite	1	
Biotite granodiorite gneiss, with mylonite relic structure	1	
Total metamorphic	18	36
Vein		
Quartz	1	
Total vein	1	2
Grand total	50	100

Twenty-three specimens from locality 4 were studied under the microscope.

The boulders and cobbles listed were collected from a residual accumulation along a ridge. The largest boulder is a roo-inch muscovite-biotite quartz monzonite. The lists for localities 3 and 4 are thought to represent fair samples from the conglomerates of the lower member of the Puente formation in the San Jose Hills. The larger clasts are of varied textures but similar composition, ranging from mica granite and quartz monzonite, and the related dike rocks, through mylonite to mica gneiss. Volcanic constituents are rare at most localities, though fairly numerous in parts of some beds.

The sandstone beds of the lower Puente in the Puente Hills, especially the thick Diamond Bar sand, are feldspathic and in most occurrences are micaceous. Some samples have granodiorite composition. Thin sections of coarse-grained sandstone from the upper part of the Diamond Bar sand, in Western Gulf Diamond Bar well No. 1, depths 933-937 and 1,449-1,455 feet, show abundant quartz and oligoclase, with orthoclase a poor third, and andesine and biotite present. A fine-grained conglomerate near the base of the Diamond Bar sand, at a depth of 3,147 feet in the same well, contains \frac{1}{2}-inch rounded pebbes of quartz, quartzite, biotite-quartz schist and gneiss, biotite-quartz porphyry, biotite granite, plagioclase-quartz pegmatite, and other rocks. Quartz diorite and granodiorite probably contributed more débris than did granite to the coarser lower Puente sediments of the Puente Hills.

Conglomerate of middle member of Puente formation, count of pebbles at locality 5 (Fig. 2, D2), southwest of Pomona, 13,300 feet north and 3,400 feet east of southwest corner of Claremont Quadrangle, top of Hill 1,200+, just inside San Jose grant, at head of tributary of San Jose Creek.

Plutonites	No. of Specimens	Per- centage
Biotite granite	2	
Anauxite ⁵ granite	4	
Biotite quartz monzonite	5	
Anauxite ⁵ quartz monzonite	4	
Biotite granodiorite	3	
Anauxites granodiorite	1	
Total plutonites	19	38
A plite, alaskite and pegmatite		
Granite aplite	4	
Garnet granite aplite	3	
Quartz monzonite aplite	1	
Garnet quartz monzonite aplite	2	
Garnet granodiorite aplite	1	
Alaskite	1	
Quartz monzonite, very pale	1	
Granite pegmatite	2	
Cavernous quartz (rotten pegmatite (?))	1	
	-	
Total aplite, alaskite, and pegmatite	16	32
Porphyries		
Mountain Meadows dacite porphyry	I	
m . 1 1 1		
Total porphyries	I	2
Volcanic		
*********	_	
Porphyritic andesite (?), rotten	<u> </u>	
Total volcanic	1	2
Metamorphic		
Granite (pegmatite?) mylonite	1	
Biotite granodiorite mylonite	1	
Biotite quartz monzonite mylonite gneiss	I	
Miscellaneous plutonite mylonites and mylonite gneisses	4	
Biotite (and muscovite) granite gneiss and quartz monzonite gneiss	3	
Graphitic quartz paragneiss (San Antonio Canyon type)	1	
Dark gray quartzite	I	
	_	
Total metamorphic	12	24

⁵ Pearly kaolinite after biotite.

Vein	No. of Specimens	Per- centage
White quartz	1	
	_	
Total vein	1	2
Grand total	50	100

Seventeen specimens from locality 5 were studied microscopically.

Sixty-two boulders, cobbles, and pebbles were collected from the selected area of outcrop. The largest clast, by far, was a boulder of biotite quartz monzonite 24 inches in diameter. The 12 pebbles not included in the count of 50 were 6 aplites, 4 alaskites, 1 mylonite gneiss, and 1 quartz. These and other observations indicate that aplites and alaskites are more abundant at locality 5, especially among the smaller pebbles, than indicated by the percentages. This is a plutonite-aplite locality, with biotite the principal accessory mineral, and garnet a notable minor one. Quartz diorite was not found. Mylonite and mylonite gneiss are the commonest metamorphic rocks. Pyrite is a common minor constituent of the fresher rocks. In many specimens biotite is partially or completely altered to anauxite (kaolinite).

Elsewhere in the large area of conglomerate of the middle Puente southwest of Pomona, the composition of the conglomerate is somewhat variable. Pegmatite cobbles are locally very abundant, with graphic texture and black tourmaline prisms 10–50 mm. long as notable features. Mylonite and mylonite gneiss are widespread but rather rare. Two mylonitic cobbles which were sectioned proved to be granite mylonite. The largest boulders in the area are biotite quartz diorite blocks, nearly equidimensional and up to 14 feet across. Perhaps such blocks rolled, bit by bit, the 2 to 4 miles from the nearest possible source. Scores of boulders, including some of the largest, are exposed southwest of the conglomerate area, some embedded in sandstone, others loose on the surface.

In most outcrops the conglomerate has a gritty or coarse sandy matrix, commonly with a calcareous cement. At locality 5 the matrix is much leached and contains some brown clay, presumably an alteration product. The clastic grains are mostly quartz, up to 3 or 4 mm. diameter. Fresh orthoclase is fairly common, fresh albite is rare, and greatly altered plagioclase somewhat less rare. No mica or anauxite was found.

In the vicinity of locality 5 the conglomerate is interbedded with grit, sandstone, sandy limestone and cherty limestone. At one locality peanut-sized conglomerate grades laterally into limestone in a distance of 18 inches.

Only one sample of the sandstone of the middle Puente has been studied microscopically. Two thin sections were prepared from a core taken at a depth of 1,740 feet in the Chino Hills Oil Company's Kraemer-Backs well No. 1, which was drilled in the eastern Puente Hills, 850 feet southwest of well 8 (Fig. 2). A rough estimate of the clastic grains is 50 per cent quartz, 40 per cent oligoclase and andesine, and 10 per cent brown biotite. No orthoclase or hornblende was seen. The cement is calcite.

One coral and marine mollusks belonging to several genera have been found in the basal pebbly sandstone and limestone of the middle member of the Puente formation, 2,000 feet S. 48° E. of summit 1,383, Claremont Quadrangle, and mollusks occur elsewhere in the same vicinity. At higher horizons a few oysters have been found. Poorly preserved foraminifera are fairly common in the interbedded limestone.

Conglomerate of middle member of Puente formation, pebble count at locality 6 (Fig. 2, B3), 4,300 feet south and 2,950 feet west of northeast corner of La Habra Quadrangle, 200 feet southwest of intersection of Fullerton (Anaheim) Road and Grazide Road, on east side of creek; lower of two prominent pebble beds at top of sandstone and siltstone of the middle Puente.

Plutoniles	No. of Specimens	Per-
Actinolite granodiorite, with epidote and sphene Biotite granite, coarse	1	
Total plutonites	2	4
Aplite, alaskite, and pegmatite		
Granite aplite	1	
Granite pegmatite, sheared, partly recryst.	1	
Soda alaskite, porphyritic	1	
m . 1 2: 1 12: 1	_	,
Total aplite, alaskite, and pegmatite	3	6
Porphyries		
Biotite soda granite porphyry, spherulitic (pseudospherulitic), sheared	1	
Fine-grained quartz monzonite porphyry with quartz veinlets	1	
A mo-Branco quarta monaomito porphyty with quarta venices	_	
Total porphyries	2	4
Volcanic		
Pale or red soda rhyolite (vitrophyre or platy felsite)	4	
Soda rhyolite (?), red	4	
Dacitic felsite, one vesicular	2	
Sodic andesite	4	
Sodic andesite with hypersthene (?)	4	
Normal andesite	4	
Normal andesite, with hypersthene (?)	1	
Pale hypersthene (?) andesite, porphyritic Hypersthene (?)-biotite calcic andesite, porphyritic	3	
Miscellaneous andesite	10	
Miscensicous andesite	-	
Total volcanic	37	74
M etamor phic		
Biotite-quartz plutonite gneiss	4	
Quartzite, medium-grained, white	2	
Total metamorphic	6	12
Grand total	50	100

From this locality 24 thin sections were studied.

The specimens at locality 6 were collected across a six-foot conglomeratic bed or lens in coarse-grained sandstone. Pebbles and cobbles are only locally abundant. The largest boulder (18 inches in diameter) is porphyritic soda alaskite. Smaller boulders and large cobbles of andesite and other rocks, 8 to 12 inches across, are fairly common. This is an andesite locality. The pebbles less than 1½ inches across (not counted) are almost all dark colored volcanic rocks. This locality is high in the middle Puente, and probably in the upper part of Kleinpell's Mohnian stage, whereas locality 5 is almost certainly lower Mohnian (Woodford, Shelton, and Moran, 1945).

Conglomerate of middle member of Puente formation, locality 7 (Fig. 2, C1), 7,500 feet south and 14,000 feet west of northeast corner of Covina Quadrangle, 1,625 feet N. 32° W. from Hill 1035, about 700 feet S. 30° W. of the abandoned loading platform for the old

Featherstone Quarries, at an elevation of approximately 800 feet.

Rounded and subrounded boulders and pebbles up to 21 inches maximum diameter. Largest boulder and several somewhat smaller are tourmaline-actinolite-albite granite. Other common types are andesite and quartzite, each in considerable variety. Less common are banded biotite aplite, a peculiar pegmatite closely related to the tourmaline granite, biotite dacite porphyry of the Mountain Meadows type, vein quartz and biotite amphibolite. A very rough estimate indicates that 40 or 50 per cent of the pebbles and boulders

are from volcanic rocks and that at least half of the remaining boulders are metam orphic Ordinary granitic and pegmatitic rocks are rare.

Five thin sections of specimens from locality 7 were studied.

Conglomerate of upper member of Puente formation, pebble count at locality 8 (Fig. 2, F4), 28,700 feet south and 24,600 feet east of northwest corner of Army Corona Quadrangle 1:62,500, in large tributary of Abacherli Creek, at elevation 925 feet.

Plutonites	No. of Specimens	Per-
Biotite granite, more or less gneissoid	3	-8
Biotite granodiorite or quartz monzonite	2	
Porphyritic actinolite granodiorite with a little tourmaline	1	
Total plutonites	6	12
Aplite, alaskite, and pegmatite		
Granite aplite	1	
Albite alaskite	1	
Total aplite, alaskite, and pegmatite	2	4
Porphyries		
Quartz monzonite porphyry	2	
Biotite quartz diorite porphyry (pale)	2	
Muscovite granophyre	x	
Dacite porphyry (pale, holocrystalline, altered)	1	
Medium dark chlorite dacite porphyry (Mountain Meadows?)	1	
Total porphyries	7	14
Volcanic		
Dacite?	1	
Biotite andesite	1	
Pyroxene andesite	1	
Miscellaneous andesites, with plagioclase mostly An 35-45 per cent	7	
Total volcanic	10	20
Metamorphic		
Biotite granite mylonite gneiss	1	
Quartz plutonite mylonite gneiss, one pale, one dark	2	
Biotite-quartz plutonite gneiss, about half granite gneiss, half quartz	-	
monzonite or granodiorite gneiss	16	
Muscovite-biotite granite augen gneiss	I	
Chloritic quartz plutonite gneiss	2	
Biotite-quartz gneiss, with feldspar, garnet, etc.	2	
Quartz with a little biotite, from a gneiss	1	
	. —	
Total metamorphic	25	50
Grand total	50	100

From this locality 24 thin sections were studied.

Locality 8 is in a well exposed section north of Mahala well No. 2 where the upper member of the Puente formation is almost all medium, or fine-grained conglomerate. The collection was made from one of the coarser beds, with cobbles up to 9 inches diameter. This bed is probably at a horizon which is represented by fine sediments (Cubierto shale of Krueger) \(\frac{1}{2}\) mile northwest.

This is a biotite gneiss locality.

Conglomerate of the upper member of the Puente formation, pebble count at locality 9 (Fig. 2, F4), 27,600 feet south and 22,350 feet east of northwest corner of Army Corona

Quadrangle 1:62,500; the 5-foot middle (coarsest) pebble bed in Krueger's 60-70 foot Hunter conglomerate, north side of south fork of upper Abacherli Canyon.

Plutonites	No. of Specimens	Per- centage
Muscovite-biotite granite, fine-grained	I	
Muscovite-biotite soda granite	I	
Muscovite soda granite	· 1	
Biotite granite, more or less gneissoid	4	
Actinolite soda granite (no potash feldspar) and quartz monzonite, two		
with tourmaline	4	
Muscovite-biotite granodiorite	1	
Biotite-(chlorite) quartz diorite	1	
Hornblende-(chlorite) quartz diorite	1	
Dark fine-grained biotite granite, probably from a schliere	1	
Total plutonites	15	30
A plite, alaskite, and pegmatite		
Granite aplite	2	
Quartz monzonite aplite	I	
•		
Total aplite, alaskite, and pegmatite	3	6
Porphyries		
Biotite-(chlorite) quartz diorite porphyry	3	
Biotite granodiorite porphyry	I	
Mountain Meadows dacite porphyry	I	
Chlorite dacite porphyry (Fig. 6F), probably Mountain Meadows	1	
Spilitized porphyritic diabase	I	
	_	
Total porphyries	7	14
Volcanic		
Dacite, (porphyritic)	1	
Albite porphyry	ī	
Altered hornblende andesite	I	
Andesite and basalt, altered	4	
Total volcanic	7	14
Metamorphic		
Biotite granite gneiss (some muscovite, some feldspar augen)	9	
Biotite quartz plutonite gneiss	4	
Chloritic granite gneiss	I	
Muscovite-biotite granodiorite augen gneiss	I	
Dark biotite-epidote granodiorite gneiss	1	
Micaceous quartzite	2	
m . 1	_	
Total metamorphic	18	36
Grand total	50	100

From this locality 21 thin sections were studied.

The largest boulder (20 inches in diameter) that was observed in the bed was a gneissoid biotite granite. The clasts in the sample were all between $1\frac{1}{2}$ and 7 inches in diameter. Supplementary study of 26 smaller ($1-1\frac{1}{2}$ inch) pebbles indicates that they run higher (35-40 per cent) in andesitic and similar volcanic rocks. An earlier count at the same locality showed a larger proportion of Mountain Meadows dacite porphyry and of pale volcanic rocks. Biotite granite, actinolite-(tourmaline) soda granite, and quartz monzonite, Mountain Meadows dacite porphyry, and biotite granite gneiss are the characteristic rocks.

In Slaughter Canyon, $\frac{5}{8}$ mile northwest of locality 9, the upper Puente includes only a little conglomerate but does contain 500–600 feet of sandstone (cf. p. 521). The Blanco sandstone of Krueger, representing a horizon somewhat lower than locality 9 (Krueger's Hunter), is an arkosic sandstone, with potash and soda-lime feldspar about equally abundant, and biotite and hornblende both fairly common. The plagioclase is in part untwinned albite, perhaps from a metamorphic rock.

Conglomerate of upper member of Puente formation, pebble count at locality 10 (Fig. 2. C2), 13,600 feet north and 14,600 feet west of southeast corner of Covina Quadrangle, at elevation of 840 feet, in old quarry.

Plutonites	No. of Specimens	Per- centage
Tourmaline-actinolite quartz monzonite		cemage
Actinolite quartz monzonite	3	
Biotite granite	3	
Muscovite quartz monzonite with biotite and epidote, (gneissoid)	1	
Gneissoid biotite granite with orthoclase eyes	9	
Total plutonites	17	34
Aplite, alaskite, and pegmatite		
Muscovite granite aplite	1	
Total aplite, alaskite, and pegmatite	1	2
Porphyries Biotite dacite porphyry of unknown affinities	1	
blotte ducte porphyry of anknown animetes	-	
Total porphyries	1	2
Volcanic		
Andesite, pale and weathered	4	
Andesite, fine-grained, dark	1	
Biotite andesite with rutile, weathered	1	
Porphyritic basalt(?), altered, bluish	7	
Total volcanic	13	26
M etamor phic		
Biotite granite gneiss	4 8	
Biotite-quartz paragneiss, coarse, with 5 cm. quartz blebs Muscovite-biotite-quartz paragneiss, 60-70 per cent quartz, fine-grained,	8	
like that of southeastern San Gabriel Mountains	2	
Biotite-quartz paragneiss, 80 per cent quartz, fine-grained, poorly banded	d 2	
Total metamorphic	16	32
Vein		
Quartz	2	
Total vein	-	
Grand total	50	100
Canada Cotta	20	100

From this locality 14 specimens were studied microscopically.

The collection was made from the lower part of an exposed section of about 150 feet of conglomerate, broken by a few lenses of sandstone and shale up to one foot thick and 20 or 30 feet long. The shale beds contain marine foraminifera and diatoms. The two largest boulders found were each about 30 inches long, one a rotten andesite(?), the other a tourmaline-actinolite quartz monzonite which probably weighs 1,400 pounds. This is a biotite gneiss and gneissoid granite locality.

Conglomerate of the upper member of the Puente formation, pebble count at locality II (Fig. 2, BI), 14,450 feet south and 6,800 feet east of northwest corner of Covina Quadrangle, 1,000 feet ESE of intersection of Cameron and Barromea Streets, on Thorpe driveway.

Plutonites	No. of Specimens	Per- centage
Tourmaline-actinolite quartz monzonite	5	
Biotite granite (or quartz monzonite)	3	
Porphyritic biotite granite (little quartz) Biotite quartz diorite or granodiorite	3	
Biodite quartz diorite or granodiorite		
Total plutonites	12	12
A plite, alaskite, and pegmatite		
Granite aplite	I	
Banded, rotten aplite	2	
Alaskite (quartz and orthoclase)	2	
Quartz-plagioclase rock, between aplite and pegmatite	1	
Granodiorite pegmatite	1	
Total aplite, alaskite, and pegmatite	7	7
Porphyries		
Quartz diorite porphyry (plagioclase and quartz phenocrysts)	2	
Diorite or andesite porphyry	1	
Dacite porphyry (no biotite)	1	
Plagioclase rock with biotite (andesite porphyry?)	1	
Total porphyries	5	5
Volcanic		
Andesite and andesite (?)	33	
Pepper and salt andesite, with sharp plagioclase phenocrysts	10	
Hornblende andesite	2	
Basalt or andesite agglomerate pebbles	2	
Biotite andesite (?) with small micas	3	
Black basalt of northeast Puente Hills type	1	
	-	
Total volcanic	51	51
Metamorphic		
Biotite quartz diorite gneiss (or gneissoid quartz diorite)	3	
Plagioclase-biotite-quartz gneiss	2	
Biotite-feldspar-quartz gneiss (2 pale, one dark)	3	
Biotite-quartz gneiss (11 well banded, 3 augen)	14	
Biotite-quartz schist	1	
Feldspathic quartzite	I	
Quartzite with tourmaline sunbursts	1	
Total metamounhic		25
Total metamorphic Grand total	25 100	25
Grand total	100	100

From this locality 6 thin sections were studied.

The pebbles at locality 11 are mostly small and well rounded, with a range in diameter of ½ to 10 inches. About one-fourth of the pebbles counted were less than one inch in diameter. About one-third of the rock is sandy matrix; the cement is ferruginous.

This is an andesite locality, with tourmaline-actinolite quartz monzonite and biotite

paragneiss as notable, but less abundant constituents.

Conglomerate of the upper member of the Puente formation, pebble count at locality 12 (Fig. 2, B2), 11,400 feet north and 800 feet west of southeast corner of Puente Quadrangle, on southeast slope of Hill 807, 1,450 feet N. 38° E. from old ranchhouse of Supreme Dairy Co.

Plutonites Biotite granite or quartz monzonite (high quartz)	No. of Specimens	Per- centage
Biotite granite or quartz monzonite with muscovite	2	
Biotite granite or quartz monzonite (gneissoid)	4	
Biotite granite or quartz monzonite with epidote	1	
Biotite granite or quartz monzonite with violet-gray quartz	1	
Muscovite-biotite granodiorite	1	
Hornblende-biotite-quartz-orthoclase rock, dark-colored, probably from		
a granite schliere	1	
m . 1 1	-	
Total plutonites	23	23
A plite, alaskite, and pegmatite		
Pegmatite and "alaskite," commonly with a little biotite, and commonly		
of granodiorite or quartz diorite composition	33	
Granite aplite, with biotite or muscovite	4	
Quartz diorite aplite (one cataclastic)	2	
Fine-grained, porphyritic aplite	2	
Granite or quartz monzonite aplite (mylonitic)	2	
Grante of quartz monzonite apare (mylonite)	-	
Total aplite, alaskite, and pegmatite	43	43
Porphyries		
Dacite porphyry without biotite	Y	
Sanidine (trachyte?) porphyry	1	
ballane (traca) to / pospsiy i	******	
Total porphyries	2	2
	-	-
Volcanic		
Pale porphyritic andesite and leached andesite (?)	19	
Andesite (?), mostly fine-grained, spherulitic feldspar	1	
Total volcanic	20	20
Metamor phic		
Biotite granite gneiss	8	
Biotite gneiss (granite gneiss (?)), rotten	4	
9 9 6		
Total metamorphic	12	12
Grand total	100	100

From this locality 10 specimens were studied under the microscope.

The conglomerate is made up of small, smooth pebbles, some of which are regular discs, spindles or spheres. The largest specimen counted was a 5½-inch spindle; the largest seen in the bed had a diameter of 12 inches. Five of the counted pebbles were less than one inch in diameter. The matrix of the conglomerate is a clean, millimeter-size, quartz-feldspar sand, with a few flakes of yellow mica.

This locality is characterized by the abundance of pegmatite, "alaskite," aplite, andesite and biotite granite or quartz monzonite. Volcanic rocks are not dominant, as they are at locality 11, which is farther northeast and probably at a slightly higher horizon.

Conglomerate of upper member of Puente formation, pebble count at locality 13 (Fig. 2, B2), east of Pass and Covina Road, 13,450 feet north and 4,050 feet west of southeast corner of Puente sheet, 1,500 feet south of Hill 654, at elevation of about 560 feet.

Plutonites	No. of Specimens	Per- centage
Biotite granite	7	
Biotite granodiorite	4	
Muscovite-biotite quartz monzonite and granodiorite	4	
Muscovite quartz monzonite with small garnets	I	
	-	
Total plutonites	16	16

Asiles Julies and homostee	No. of	Per-
A plite, alaskite, and pegmatite	Specimens	centage
Alaskite, white granodiorite, and similar very pale plutonites, in part de		
cayed	20	
Muscovite granite or quartz monzonite aplite	2	
Miscellaneous aplite, mostly with a little biotite	. 7	
Pegmatite: plagioclase not rare, but more potash feldspar	11	
Fine-grained granodiorite pegmatite	1	
Vein or pegmatite quartz	1	
77 - 1 N: 1 11: 1 - 1:	-	
Total aplite, alaskite, and pegmatite	42	42
Porphyries		
Biotite diorite porphyry(?), rotten	1	
T-4-1		-
Total porphyries	1	1
Volcanic		
Sanidine porphyry (trachyte?)	I	
Soda rhyolite (porphyritic)	2	
Soda rhyolite, dacite or andesite (rotten)	6	
Andesite(?), mostly spherulitic feldspar; rotten	1	
	-	
Total volcanic	10	10
Metamor phic		
Hornblende granite gneiss	1	
Biotite-quartz-feldspar orthogneiss, largely granite gneiss. Some rotter		
and feldspar indeterminate. Some with muscovite	24	
Biotite-quartz-feldspar mylonite orthogneiss	2	
Biotite-quartz paragneiss	3	
Muscovite-biotite-orthoclase-quartz paragneiss	3	
Manager and District of thousand dam on baraginess		
Total metamorphic	31	31
Grand total	100	100

From this locality 10 thin sections were studied.

This conglomerate, like that at locality 12, is composed of small, well-rounded pebbles. Those counted range from 1 to 3½ inches in maximum diameter. There are a few much larger boulders nearby. The largest, 3 feet across, is an actinolite-quartz plutonite. Locality 13 is farther west than locality 12, and at a higher horizon, probably about the same as that of locality 11. Locality 13 yielded far less andesite than did either of the others. It is a biotite plutonite-pegmatite-aplite-orthogneiss locality.

Conglomerate of upper member of Puente formation (Krueger's Sycamore Canyon formation), pebble count at locality 14 (Fig. 2, A3), 11,275 feet south and 11,200 feet east of northwest corner of La Habra Quadrangle, on paved road west of Hacienda Boulevard (Hudson

Road), about 500 feet northeast of Hill 1,002, at elevation of about 875 feet.

Plutonites	No. of Specimens	Per- centage
Muscovite-biotite granite, in some cases gneissoid	0	
Biotite granite, in some cases gneissoid	5	
Muscovite-biotite quartz monzonite, in some cases gneissoid	4	
Biotite quartz monzonite	I	
Muscovite-biotite granodiorite, porphyritic	I	
Biotite quartz diorite	I	
Biotite quartz diorite, gneissoid (Dudley's Perris type)	I	
White syenite(?), rotten	I	
	-	
Total plutonites	20	40

A plite, alaskite, and pegmatite	No. of Specimens	Per-
Muscovite granite aplite		
Pegmatitic quartz diorite aplite	1	
Togination dans in divite abuse		
Total aplite, alaskite, and pegmatite	3	6
Porphyries		
Dacite (or soda rhyolite) porphyry, with altered biotite	4	
Albitized dacite (and silicified andesite?) porphyry	3	
Biotite granodiorite porphyry	I	
White granophyre with albite	1	
Andesite or dacite (oligoclase) porphyry	I	
Total porphyries	10	20
Volcanic		
Andesite (porphyritic)	I	
4 1 7 /	_	
Total volcanic	1	2
Metamorphic		
Muscovite-biotite granite gneiss	I	
Biotite granite gneiss	_	
Biotite quartz monzonite gneiss	3 5	
Biotite quartz diorite gneiss, with muscovite	ī	
Biotite-quartz paragneiss, somewhat feldspathic	5	
Feldspathic quartzite	1	
	-	
Total metamorphic	16	32
Grand total	50	100

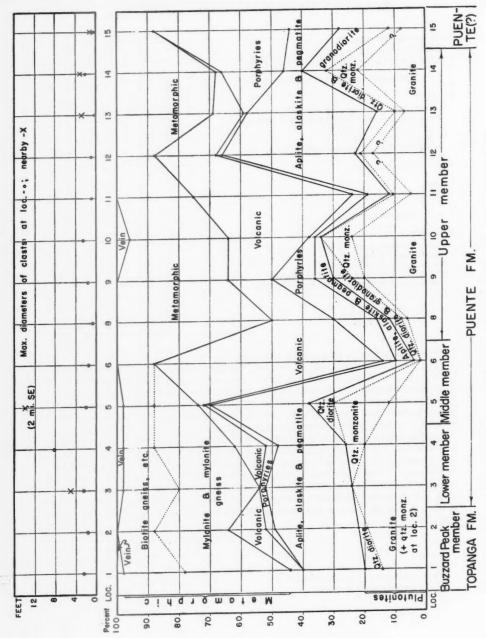
From this locality 17 thin sections were studied.

The sample was taken across a 5-foot bed. The largest clast sampled was a boulder of biotite granite 26 inches in diameter. In the whole exposure of several hundred feet of conglomerate, continuous except for a few sandstone breaks, most cobbles and pebbles are 1½ to 12 inches across, a few are between 12 and 18 inches, and a very few are between 18 and 36 inches. Most pebbles, cobbles, and boulders are subrounded or subangular. The matrix is a clean sand composed of quartz, feldspar and mica.

Biotite granite and quartz monzonite, and the corresponding gneisses, are abundant at locality 14. Biotite-quartz paragneiss is a notable constituent. Volcanic rocks are rare. The assemblage is similar to those described by Bellemin (1940, pp. 652-56), from his localities 1, 2, 3, and 4, which are also in Krueger's Sycamore Canyon formation.

Conglomerate of uppermost Miocene or lower Pliocene age, count of pebbles at locality 15 (Fig. 2, G5), 200 feet north and 1,100 feet west of southeast corner of Sec. 13, T. 3 S., R. 8 W., S.B.B. & M., 800-900 feet south of Mahala well No. 1. Elevation approximately 1,050 feet.

Plutonites	No. of Specimens	Per- centage
Muscovite granite or quartz monzonite (one with epidote)	2	
Biotite granite or quartz monzonite (pale)	1	
Biotite granodiorite (2 very pale)	3	
Muscovite granodiorite	I	
	dutemo	
Total plutonites	7	28



Frc. 8.-Diagram showing variation in abundance of rock types at 14 conglomerate localities.

A plite, alaskite, and pegmatite	No. of Specimens	Per- centage
Muscovite granite pegmatite	1	
Muscovite granite aplite	1	
Garnet-biotite granodiorite aplite	I	
Quartz diorite aplite with pyrite	I	
	-	
Total aplite, alaskite, and pegmatite	4	16
Porphyries		
Biotite granodiorite porphyry Dacite and dacite porphyry, some with biotite; certainly not Temescal Wash, probably not Mountain Meadows; may include some pale	3	
andesite	8	
	_	
Total porphyries	11	44
Metamorphic		
Dark, eyed granite mylonite gneiss	T	
Biotite granite gneiss (pink, fresh)	1	
Thin banded, micaceous quartz gneiss	1	
Total metamorphic	3	12
Grand total	25	100

Three rocks from locality 15 were studied under the microscope.

The largest pebble (5 inches in diameter) that was found at the collecting locality was dacite porphyry. The same bed, within a radius of 100 yards, yielded cobbles up to eight inches in diameter, mostly like those represented in the count, but including also fine-grained biotite quartz monzonite of southeastern San Gabriel Mountains type, vein quartz

and coarse biotite granite of the type common at localities 13 and 14.

The Mahala conglomerate of Krueger (1942), exposed a few hundred feet north and stratigraphically a few tens of feet lower than locality 15, is similar in composition, but with a smaller percentage of porphyries. The largest clast found in the Mahala conglomerate was an elongate-rounded boulder of biotite granite, 12 inches long. Several cobbles of biotite porphyry up to 8 inches across were collected. These included both granodiorite porphyry of the type represented in the foregoing count, and the typical Mountain Meadows dacite porphyry. Biotite granodiorite mylonite gneiss from the Mahala conglomerate was studied in section, and similar mylonitic rocks are fairly numerous as small pebbles, probably amounting to 3 or 4 per cent of the total number.

Krueger's Mahala (upper Puente or Pliocene) conglomerate at locality 16 (Fig. 2, F4), approximately 1,600 feet west and 200 feet south of northeast corner of Sec. 3, T. 3 S., R. 8 W., S.B.B. & M., halfway up northwest side of the east ravine at the head of the east fork of Aliso Creek, eastern Puente Hills, elevation approx. 1,100 feet. Conglomerate lens in sandy siltstone, near north limit of Mahala pebbles. Rounded pebbles, cobbles and boulders up to 14 inches in length. Some pebbles are quartz, but most of them are quartz-feldspar rocks such as aplite (including muscovite granite aplite, biotite granite aplite and garnet-muscovite soda granite aplite), alaskite and muscovite soda granite pegmatite. Some boulders of biotite granite, muscovite soda granite and white granodiorite are present. The soda granite aplite and pegmatite contain orthoclase as well as albite. Two or three three-inch rounded pebbles of biotite-albite porphyry and spherulitic albite porphyry (Fig. 5D). From this locality 6 thin sections; 2 rocks studied in oils.

Locality 16 represents a conglomerate in which quartz-rich plutonic rocks have been concentrated; the typical specimen is perhaps a muscovite granite aplite.

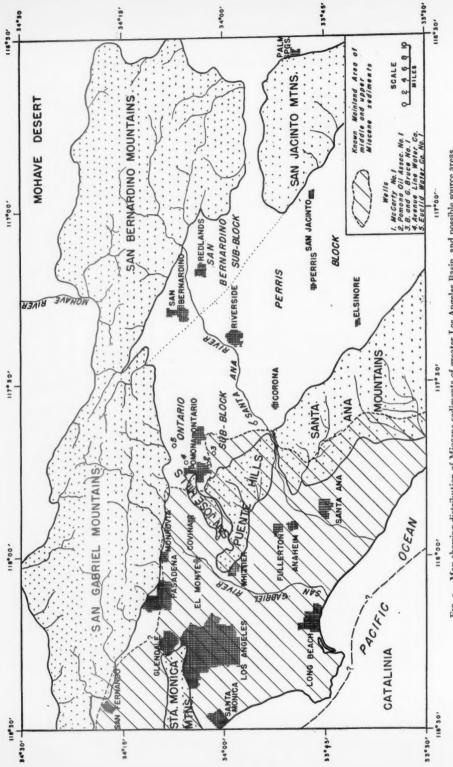


Fig. 9.-Map showing distribution of Miocene sediments of greater Los Angeles Basin, and possible source areas.

Locality 16 is in the summit area of the Ridge syncline, only a few hundred yards west of the east-facing escarpment along which Krueger's Mahala conglomerate extends south and southeast in discontinuous outcrop for several miles, as shown in Figure 2. Southwest of locality 16, in sections 3 and 10, the conglomerate is represented by one extensive thin bed, one thick lens a half mile long, and many smaller lenses, not shown in Figure 2. Some lenses are only one or two feet thick and 20 or 30 feet long, with most of the pebbles under two inches in diameter but with occasional boulders 14, 15, or even 18 inches across. The matrix of the pebbles is commonly just like Krueger's Peculiar "shale," a structureless micaceous silty fine sandstone. There are even isolated cobbles in the "shale." Pebbles, cobbles and boulders are mostly quartz-rich plutonic, aplitic or metamorphic rocks, with some rather rotten porphyries and volcanic rocks and occasional pebbles of vein quartz and quartzite. Biotite granite and granite aplite are present and probably common.

POSSIBLE SOURCE AREAS

The middle and upper Miocene sediments of the Puente and San Iose Hills are continuous with those of the Los Angeles Basin proper, which extends from Whittier to the sea. Other contemporaneous deposits extend farther south and northwest (Fig. 9). The surrounding areas, which are more or less possible sources for the Miocene pebbles and other clastic sediments, are as follows (listed clockwise).

- Western San Gabriel Mountains, west of Long. 117°52'.
- Western San Gabriel Mountains, east of Long. 117°52', north of Lat. 34°15'. Southeastern San Gabriel Mountains, east of Long. 117°52', south of Lat. 34°15'.
- 3. San Bernardino Mountains.
- San Jacinto Mountains.
- Perris block
- 6-A. Ontario sub-block,—the northwestern part of the Perris block covered by the alluvium of the upper Santa Ana basin or Ontario plain
- Eastern Santa Ana Mountains
- Catalinia (R. D. Reed, 1933, p. 116)
- Eastern Santa Monica Mountains

The rocks of Catalinia include the very distinctive glaucophane and related schists (Woodford, 1924), which are not known from the other bedrock areas. In all the other possible source areas quartz plutonites or biotite gneisses, or both, bulk large, and distinctions must be made on the basis of exceptional minor types or by rather thorough studies, both of source areas and conglomerates. No plutonite-gneiss source area has yet been studied in adequate detail, but some of the known facts are suggestive.

Western San Gabriel Mountains (west of Long. 117°52').—From the map by W. J. Miller (1934), supplemented by the work of Arnold and Strong (1905), Gordon Oakeschott (1938), and observations of the writers, it is estimated that rock types in the San Gabriel Mountains west of Long. 117°52' (approximately the line of the lower San Gabriel River), at the present time have the following areal percentages.

	Percentage
Anorthositic and related rocks	20
Leuco-granodiorite, dark minerals rarely above 3 per cent (Lowe granodiorite of Mille	r,
in part the same as the "dappled diorite" of E. C. Edwards, 1934, p. 790)	27
Massive hiotite granite ("Mount Waterman" granite of Arnold and Strong)	16

	Percentage
Gneissoid hornblende-biotite quartz diorite (Wilson diorite of Miller)	9
San Gabriel metamorphic complex, Placerita metasediments, Echo granite gneiss and	
Rubio hornblende diorite (terms from Miller)	28
Total	100

Here the characteristic rock is anorthosite, which is found only in the northern part of the area. Two anorthosite pebbles were found by Bellemin (1940, p. 657) in the uppermost Miocene conglomerate at the west tip of the Puente Hills. The "Mount Waterman" granite is not exactly like the granites of the other possible source areas and is very like the granite abundant in some of the Miocene conglomerates.

Northeastern San Gabriel Mountains (east of Long. 117°52', north of Lat. 34°15', approximately east of line of lower San Gabriel River, and north of Cattle and Icehouse Creeks).—From unpublished maps and reconnaissance by Levi Noble, Stanton Hill, and others, the following very general areal percentages are hazarded.

	Percentage
Pelona schist: chiefly rocks rich in albite and chlorite, with dark and lustrous foliation	
surfaces	56
San Gabriel metamorphic complex	8
Biotite granite	2
Leuco-granodiorite, dark minerals (biotite and hornblende) rarely more than 3 per cer	
Granitic and gneissic rocks northeast of the San Andreas rift	26
m-1	-
Total	100

A distinctive and resistant element in the Pelona schist is piedmontite-quartz schist. It makes up a very small fraction of one per cent of the Pelona outcrop area, but may be as common as one pebble per thousand in portions of the Recent stream gravels of San Gabriel River and Lytle Creek, and more abundant in some older gravels of the region (cf. Webb, 1939). It has not been found by us in the conglomerates of the Puente and San Jose Hills. An abundance of albite in a sandstone may suggest derivation from the Pelona schist, though there are several other possible sources for albite.

Southeastern San Gabriel Mountains (east of Long. 117°52', south of Lat. 34°15', approximately east of the line of lower San Gabriel River, and south of Cattle and Icehouse creeks).—From unpublished maps and reconnaissance by Robert T. Bean, Raymond M. Alf, A. O. Woodford and others, the following very general areal percentages are hazarded.

	Percentage
San Gabriel metamorphic complex	46
Pelona schist	3
Paleozoic quartzite, in part pyritic and rusty weathering	3
Paleozoic metamorphosed limestone, with lime silicates	2
Mountain Meadows dacite porphyry, mostly between San Gabriel and San Antonio	
canyons	2
Mylonite and mylonite gneiss, mostly along south edge of range east of San Antonio	
Canyon	8
Biotite quartz monzonite (fine-grained), locally with orthoclase phenocrysts	5
Hornblende-biotite quartz diorite and quartz diorite gneiss	31
	-
Total	100

A very rare but distinctive facies of the crystalline limestone contains lapis lazuli Hundreds of fragments of this rock have been found along San Antonio Creek, some small pebbles as much as 9 miles downstream from the outcrop. As yet lapis has not been found in the Miocene conglomerates. The belts of mylonite rocks and their general petrographic character have been described briefly by Raymond M. Alf (1943). Pegmatite dikes are numerous and they contain some black tourmaline, a mineral almost unknown in the crystalline rocks west of this area, but abundant in the Perris block.

West of the vincinity of San Dimas Canyon, the mountain front is bordered by narrow strips of normal and calcic andesite and andesite breccia, probably middle Miocene in age, which in general are in fault contact with the bedrock. These volcanic rocks may have formed quite an extensive cover on the bedrock, and they may have been largely removed by erosion in late Miocene time.

San Bernardino Mountains.—F. E. Vaughan (1922) has furnished a very useful map and description covering practically all that portion of the range which lies east of 117° W. Long. Approximate percentages of the various rock types have been calculated from Vaughan's map, with some slight modifications suggested by Woodford and Harriss (1928).

	Percentage
Cactus biotite (muscovite) granite of Vaughan, locally with orthoclase phenocrysts; myrmekite and graphic intergrowths present; locally hornblende present	21
Varied granitic rocks, notably leuco-granite or alaskite (aplite); also some quartz diorite; dark minerals biotite and rarely hornblende	29
Undifferentiated schists and gneisses; mica (biotite-quartz) schist, biotite granite gneiss, et cetera. Much pegmatite; some hornblende gneiss	34
Quartzite: chiefly massive white, in less amount thin-bedded gray	9
Limestone: massive, white or gray, in part dolomite	7
	-
Total	100

The part of the San Bernardino Mountains west of 117° is largely made up of Vaughan's Cactus granite and other plutonic rocks. In the range as a whole, quartz plutonites probably are exposed over more than half of the area.

No volcanic rocks of Miocene or earlier geologic age are known in the San Bernardino Mountains. The remnants of olivine basalt flows which are distributed around the margins of the eastern part of the range are considered probable early Quaternary by Vaughan (1922, p. 384).

San Jacinto Mountains.—D. M. Fraser (1931) has furnished a map and description of the San Jacinto Quadrangle south of San Gorgonio Pass, including both the San Jacinto Mountains and the lower plateau country south of them. Approximate percentages of the crystalline rocks of this area, as far east as Palm Canyon and Palm Springs, have been calculated from Fraser's map.

	Percentage
Metamorphic series, mostly mica schist, some hornblende schist, limestone and quartz-	
ite "Granite": mostly biotite-hornblende (or biotite) quartz diorite and granodiorite; some	18
quartz monzonite, some biotite granite	77

Dynamometamorphic biotite quartz diorite, along Palm Canyon (possibly in part my	Percentage
lonite gneiss)	4
Gabbro	1
T	***************************************
Total	100

Perris block.—The plateaus and low mountains in the central part of the Perris block, from Riverside at the north to Elsinore at the south, have been mapped by Paul H. Dudley (1936). His area is immediately west of the San Jacinto Quadrangle and extends almost to the Santa Ana Mountains. The approximate percentages of the rocks of the area were calculated from Dudley's map, with the slight modifications indicated by Osborn (1939).

	Percentage
Elsinore ⁶ metamorphic series: dense mica-quartz schist, more or less fissile slates, felds-	
pathic quartzite, varicolored metavolcanic rocks, etc.	14
Temescal Wash dacite porphyry: dark-colored biotite quartz feldspar porphyry	8
Perris hornblende-biotite quartz diorite (Bonsall tonalite of E. S. Larsen and associates,	
of. C. S. Hurlbut 1935; Valverde tonalite of Osborn 1939), a coarse-grained banded	
rock containing numerous dark finer-grained schlieren	53
Massive, pale biotite-hornblende granodiorite and quartz diorite	
Coarse, massive, pale biotite granite and quartz monzonite (Cajalco6 quartz monzonite)	8
Gabbro and norite	4
	-
Total	100

Pegmatites are common locally, probably more so than in any other possible source area. At the old Cajalco Tin Mine the pegmatites and quartz veins are dark owing to the presence of black tourmaline. Northwest of Dudley's area, in the Jurupa Mountains west of Riverside, where rather dark-colored quartz diorite or granodiorite (Perris quartz diorite of Dudley) is the principal rock, the arid hillsides are striped with pale dikes of granite pegmatite. Most of these pegmatites are composed of quartz, microcline, some oligoclase, and occasional prisms of black tourmaline. Some dikes are banded, with the outer bands composed of intergrowths of quartz and albite (Daly, 1935). Small pink garnets are commonly present in the finer-grained layers, especially in the normal, non-albitic pegmatites.

Ontario sub-block.—The alluvium-covered northwest part of the Perris block is here called the Ontario sub-block (Fig. 9). It lies immediately northeast of the Puente and San Jose Hills. It is bounded on the north by the San Gabriel Mountains and on the northeast, across the San Jacinto fault, by the small, triangular San Bernardino Basin block. The Ontario sub-block and the San Bernardino Basin block have a continuous lowland surface which was called the Ontario Valley by R. T. Hill (1928, p. 88).

Five wells that have furnished information concerning the bedrock in the western part of the Ontario sub-block are shown in Figure 9. They are here listed

Dudley's names.

with the names of the rocks penetrated. The first three wells were drilled for oil.

R. A. Nickell's McCarty No. 1, biotite-hornblende granodiorite (core), top at depth of 1,241 feet Pomona Oil Association's Community No. 1, biotite quartz diorite (core), top at depth of 880 feet B. & G. Development Co.'s Bruce No. 1, hornblende-biotite quartz diorite (ditch samples), top at depth of 2,600 feet

Avenue Line Mutual Water Co.'s well (Calif. Div. Water Res. No. 663m), Mountain Meadows dacite porphyry (ditch sample), top at depth of 700 feet Euclid Water Co.'s No. 6, gray gneiss and pink pegmatite (ditch sample), top at depth of 715 feet

The rocks struck by the first four wells are similar to those in the outcrops of basement rocks at the edges of the Puente and San Jose Hills. The granodiorite of the McCarty well is also similar to the principal rock in the exposed portions of the Perris block, not far away. The samples from the Ontario sub-block are like the rocks of the adjacent high lands, but most of the mass has not even been sampled.

Eastern Santa Ana Mountains.—The pre-Upper Cretaceous bedrock of the Santa Ana Mountains has been studied by Bernard Moore (abstract, 1931) and Rene Engel (abstract, 1932). Moore's unpublished maps and thesis, kindly made available by the California Institute of Technology, cover the central part of the mountains, south of Silverado Canyon and west of Long. 117°30'. He differentiated large areas of slate, sandstone, limestone, and conglomerate, in part definitely Triassic, extensive chloritized andesite and dacite intrusive porphyries, and some extrusive andesite and dacite lavas interbedded with soapy, green, quartz-bearing tuffs. These rocks are intruded by two broad tongues of granodiorite, considered to be parts of the Peninsular batholith.

The Triassic (?) sandstone is a distinctive, dark gray rock, commonly partially recrystallized. It is very different from the Cretaceous or Tertiary sandstones on the one hand and the Paleozoic quartzites of the San Bernardino and San Gabriel Mountains on the other. No example of Triassic (?) sandstone has been seen in the Miocene conglomerates of the Puente and San Jose Hills.

Catalinia.—The characteristic glaucophane-lawsonite-albite rocks of Catalinia have not been found in the Miocene conglomerates of the Puente and San Jose Hills. Their absence is of interest, because these rocks make up the middle Miocene San Onofre breccia of the southwestern margin of the Los Angeles Basin (Woodford, 1925).

Eastern Santa Monica Mountains.—At the east end of the Santa Monica Mountains in the city of Los Angeles, erosion has cut through the Miocene and other sediments to expose some 28 square miles of metamorphic and plutonic rocks, which were mapped by Hoots (1931, Pl. 16) as approximately 28 per cent biotite granite, hornblende biotite granodiorite, et cetera; 44 per cent slaty rocks; 21 per cent slate spotted with cordierite (?), and 7 per cent contact schist and phyllite. As the upper Miocene (Modelo) sediments overlie this basement complex uncomformably, it must have been exposed to erosion during part of middle-Miocene time.

CONCLUSIONS

Depositional environment.—All the conglomerates either contain marine fossils or are interbedded marginally with fossiliferous marine sediments. It is possible that portions of some conglomerates, such as the Buzzard Peak conglomerate of the Topanga formation, may have been sub-aerial accumulations, but it seems certain that deposition was chiefly marine.

Sizes and sorting of clasts.—There are giant boulders in the lower and middle members of the Puente formation near the northeast margin of the area. In general, as shown in Figure 8, the younger conglomerates are less coarse than the older. As shown in Figure 2, the younger conglomerates are more numerous and more widespread. It may be, as suggested in Figures 10 and 11, that the upper Puente basin was larger than its predecessors and that we merely do not find in the Puente and San Jose Hills the coarsest marginal boulder beds of the upper Puente.

The sorting of the Buzzard Peak conglomerate and the conglomerates of the lower Puente appears to be especially poor. The larger clasts are of varied sizes and the sandy matrix probably makes up at least 50 or 60 per cent of the rock. The matrices of all the conglomerates are sandy with little or no silt or clay. More precise description of the sorting is impossible because no mechanical analyses were made. An adequate analysis of a coarse conglomerate is very laborious and several such analyses from each member would be necessary to give statistically useful figures.

Composition of clasts.—Three types of rocks which are common in the region have not been found in the conglomerates; these are glaucophane and related schists, anorthosite, and unmetamorphosed sediments. The absence of glaucophane schist, saussuritized gabbro, et cetera, demonstrates that Catalinia (Fig. 9) did not furnish material to these conglomerates. The absence of anorthosite indicates that the northwestern San Gabriel Mountains area did not contribute. The rarity of unmetamorphosed sediments suggests that contributions from Upper Cretaceous or earlier Tertiary terranes were slight or lacking, especially as the Cretaceous sandstone concretions and the Miocene cherts would make durable and striking pebbles.

The pebbles and boulders in the conglomerates are predominantly (1) quartz-rich plutonic rocks, dike rocks and gneisses, and (2) calcic volcanic rocks, mostly andesites. In the plutonic and gneissic rocks of the conglomerates, biotite is almost the only dark mineral, whereas in the commonest plutonic rocks of the source areas, hornblende is almost as abundant as biotite. Therefore the conglomerates under consideration cannot be matched as closely with the rocks of any possible source area as the San Onofre breccia (Woodford, 1925) can be matched with the rocks of Catalinia. The best we can hope for is to find some distinctive pebble types which can be traced to their sources, and to use as checks the general character and percentages of the more abundant, seemingly less distinctive types, such as biotite granite or biotite gneiss. Two possible explana-

tions for the rarity of hornblende rocks in the conglomerates will be discussed after considering sources for the Topanga and lower Puente clasts.

Sources of detritus in Topanga formation.—That the Buzzard Peak conglomerate was derived from the northeastern half of the geographic circle is indicated by its gradation southwest into siltstone and shale. A more definite indication of source is given by the abundance in the conglomerate of mylonite gneisses practically identical with those exposed at the mouth of Cucamonga Canyon and elsewhere in the southeastern San Gabriel Mountains. The occasional pebble of the Mountain Meadows dacite porphyry points in the same general northeasterly direction. The coarse sandy matrix, high in quartz and plagioclase, suggests contributions from quartz diorite which is common in the southeastern San Gabriels and also in the immediately adjacent Ontario sub-block. The pebbles of biotite granite are of doubtful origin; possibly they came from a mass in the Ontario sub-block, now hidden by alluvium; possibly they indicate a contribution from the "Mount Waterman" granite in the east part of the western San Gabriel Mountains. However, it is evident that one principal source area was east and northeast of the conglomerate outcrop.

The presence of andesite boulders in the Buzzard Peak conglomerate probably indicates that the slightly older volcanic rocks were already being eroded, but the rarity of these boulders shows that the andesite formed an insignificant part of the mass undergoing erosion.

Sources of conglomerates of lower member of Puente formation.—The circumstances and the evidence are the same for the lower Puente as for the Topanga. Conglomerates of the lower Puente are restricted to the northeast end of the San Jose Hills and the boulders, some of which are very large, are composed chiefly of granite, granite pegmatite, plutonite mylonite, and biotite gneiss. There are also pebbles of biotite quartz monzonite of the fine-grained, southeastern San Gabriel type. Volcanic boulders are present, but rare. Probably boulders came from the southeastern portion of the San Gabriel Mountains and from adjacent area, though the abundance of granite and rarity of quartz diorite are puzzling features.

Possible causes for rarity of hornblende-bearing rocks in conglomerates.—If, as seems probable, the southeastern San Gabriel Mountains were a principal source area for the Buzzard Peak and the conglomerate of the lower Puente, we have a definite example of a difficulty previously mentioned. Why are there not numerous boulders of hornblende-biotite quartz diorite gneiss in the conglomerates? Such boulders choke the canyons of the eastern San Gabriel range. They are perhaps somewhat less abundant and less fresh on the present alluvial fans. Nevertheless, Bellemin (1940, p. 666) found hornblende-bearing pebbles and boulders about one-half as common in San Antonio Wash as those with biotite alone. The ratio in the conglomerates must be as low as 1:30. Possibly hornblende-bearing clasts which have travelled farther than those in San Antonio Wash, or moved in a different environment, decay and disintegrate with excep-

tional rapidity. Bramlette (1941) has shown that hornblende is an unstable mineral in sandstone. Possibly even in a crystalline boulder, moving slowly down stream channels, frequently buried and as frequently exhumed, hornblende is a source of weakness. Possibly sea water is a particularly effective reagent for hornblende decay.

It is also possible that at the higher levels in the crystalline rocks at which erosion worked in Miocene time hornblende-bearing rocks were less abundant

than they appear at present.

Sources of main (Pomona) mass of conglomerate of middle member of Puente formation.—The conglomerate of the middle Puente southwest of Pomona has two striking features. First and more obvious is the presence of a few very large, rounded boulders of biotite quartz diorite, 5 to 14 feet in diameter. These are found not only in the area of conglomerate outcrops but also 2 or 3 miles farther southwest as isolated boulders in the sandstone of the middle Puente. The rock is very similar to the quartz diorite outcropping and struck by wells in the Pomona-Chino area: it obviously had a local source and points to a shore line almost at the present edge of the middle Puente sediments. The other distinctive feature of this conglomerate of the middle Puente becomes apparent upon study of the small boulders and pebbles. Granite aplite, alaskite, pegmatite, and pale biotite granite and quartz monzonite predominate, with granite mylonite gneiss fairly common and Mountain Meadows dacite porphyry and volcanic rocks rare. Locally, the pegmatites and aplites are much more common than indicated in the list for locality 5. The composition of the bulk of the conglomerate reinforces the evidence from the large boulders, and indicates (1) a near-by, northeastern source (in the Ontario sub-block) and (2) a concentration of quartz-rich rocks from a larger area of erosion to provide the bulk of the sediments. Again the exact source of the biotite granite is a problem. Perhaps it came from that large portion of the Ontario sub-block which has not been sampled by wells. Volcanic rocks, if present in the region of erosion, decayed to such an extent that few pebbles of them survived. Perhaps the most unusual feature of this conglomerate is the abundance of anauxite after biotite. A few cases of single boulders containing superficial anauxite and central biotite suggest the possibility that the anauxite was formed in the present cycle, but even this evidence is not inconsistent with formation at the time and in the area of deposition of the conglomerate. No interbedded anauxite sandstones have been found.

Sources of conglomerates of middle member of Puente formation in western Puente Hills.—Conglomerates at the top of the middle member of the Puente formation near Fullerton Road (locality 6) are made up chiefly of andesite and other volcanic pebbles. Normal and acid andesite predominate, suggesting possible derivation from the Pomona lobe of the Glendora (Topanga) volcanic field (cf. Figs. 2 and 10). The source of the reddish soda-rhyolite pebbles and cobbles is unknown.

Sources of conglomerates of the middle and upper members of the Puente formation of San Jose Hills.—The conglomerates represented by localities 7, 10, and 11 are distributed through some 1,500 feet of strata, the lowest bed being called here middle Puente and the rest, which are interbedded with sandstone, siltstone, and shale, being called upper Puente. All are similar in distribution, character of the strata, and composition of the pebbles.

At localities 7, 10, 11 volcanic pebbles are first in abundance. Where fresh enough for determination, they are commonly calcic andesite, similar to the prevailing rock in the Glendora volcanics. The Glendora volcanics now are exposed north and northeast of the main mass of the San Jose Hills. The appearance of abundant volcanic pebbles in these conglomerates of the middle and upper Puente suggests that the Topanga rocks began to be eroded at this time.

Rarer at localities 7, 10, and 11, but more striking, is tourmaline-actinolite granite or quartz monzonite, because of its unusual appearance and composition and also because of the frequently large size of the boulders, up to an observed maximum of 31 inches in diameter and estimated 1,400 pounds weight at locality 10. The large size and common occurrence of these boulders indicates a relatively nearby source which therefore must be in the northeast half of the geographic circle (cf. Fig. 9). No such rock is known anywhere in the basement complex and so the exact source of these boulders remains uncertain. It should be noted that this rock is only moderately similar to the tourmaline-bearing Cajalco granite or quartz monzonite of the Perris block and that not one dark tourmaline-quartz pebble of Cajalco type has been found. By contrast, Russell Simonson (quoted by Soper, 1938, p. 141) found the full suite of Cajalco tourmaliniferous types in the conglomerate in the lower part of the Sespe formation of the central Santa Monica Mountains, 65–70 miles from their apparent source.

The conglomerates of the upper Puente, probably uppermost Puente, near the west end of the San Jose Hills, represented by localities 12 and 13 just east of Pass and Covina Road, are somewhat different from those at localities 10 and 11 on the northeast. Volcanic rocks are less abundant and include soda rhyolite and other alkalic rocks, and (tourmaline) actinolite granite is very rare. Biotite granite or quartz monzonite, quite similar to the "Mount Waterman" granite of Arnold and Strong (1905) and apparently identical with Bellemin's (1940) conglomerate granite, is a common constituent. Strangely enough, the abundant, almost predominant pegmatitic and aplitic rocks belong chiefly to the granodiorite and quartz diorite group though granite-aplite and pegmatite are not rare. The ensemble suggests a possible source in the northeastern part of the western San Gabriel Mountains, with the possible elimination of hornblende-bearing granodiorite during weathering and transportation.

Source of conglomerates in upper member of Puente formation in western Puente Hills.—These coarse grained and extensive conglomerate beds (part of Krueger's Sycamore Canyon formation) are similar to those described by Bellemin (1940)

from the area just at the west. As studied at locality 14, biotite granite and muscovite-biotite granite are very common, with biotite gneiss the next common rock. Here again the evidence is rather inconclusive, perhaps pointing toward the west-central San Gabriel Mountains as the most probable source area.

Sources of conglomerates of upper member of Puente formation of southeastern Puente Hills.—The conglomerates of the upper Puente of the southeastern Puente Hills, including Krueger's conglomerate of possibly basal Pliocene age, reach their maximum thickness in the almost continuous conglomerate section between lower Abacherli Canyon and the Mahala No. 2 well (Fig. 2, G 4-5). The conglomerates below Krueger's Mahala conglomerate run out into sandstone or even into shale when followed northeast, and all the conglomerates grade out or pinch out to the west (Fig. 2). These facts suggest probable sources east or southeast of the Puente Hills. However, the two most distinctive rocks of the nearby parts of the Perris block as now exposed are either missing or very rare in the conglomerates. Neither Temescal Wash dacite porphyry nor the very dark colored tourmalinequartz rock of the Cajalco district has been found. On the other hand, Mountain Meadows dacite porphyry, tourmaline-actinolite soda granite or quartz monzonite and granite mylonite gneiss are present in small percentages. The really abunnant rocks in these conglomerates are quartz-rich biotite gneisses, especially biotite plutonite gneiss, and granite aplite and pegmatite, commonly with muscovite and albite. The gneisses are not distinctive, but similar rocks are perhaps most common in the southern San Bernardino Mountains. The albite aplite and pegmatite are somewhat, but not exactly, like those of the northern Perris block a few miles east. Possibly the pebbles were derived from a wide arc, including rather definitely the southeastern part of the San Gabriel Mountains, as indicated by the mylonite gneiss and perhaps by the Mountain Meadows dacite porphyry.

WHENCE THE TOURMALINE-ACTINOLITE PLUTONITES?

Quartz plutonites with pale green actinolite patches and scattered tourmaline needles (Fig. <B) have been found as pebbles, cobbles and boulders up to an estimated weight of 1,400 pounds, especially in the conglomerates of the upper Puente of the central San Jose Hills. No closely similar rocks are known in the adjacent crystalline terranes. They may yet be found, perhaps in the southeastern San Gabriel Mountains, an area whose petrology has been little studied. It is also possible that this particular plutonic facies has been wholly removed from the basement complex by erosion.

CONTEMPORANEOUS CONGLOMERATES IN ADJACENT AREAS

Thick and extensive Miocene conglomerates occur along most marginal portions of the greater Los Angeles Basin and also at the west end of the San Gabriel Mountains, in the Ventura Basin. All would require consideration in a general study of the Miocene geography of the Los Angeles Basin. Of the contemporaneous conglomerates in other Los Angeles Basin areas only those of the San Gabriel

foothills, between Pomona and Monrovia (Fig. 9), have been examined in connection with the present investigation. They seem to have been derived from the basement rocks of the San Gabriel Mountains, with mylonite pebbles indicating easterly as well as northern sources.

The conglomeratic Potato sandstone, which occupies several square miles in the southwestern San Bernardino Mountains, was tentatively correlated with the Puente formation by Vaughan (1922, p. 364). The Potato sandstone is arkosic,

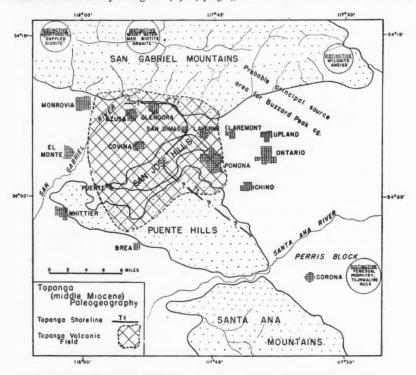


Fig. 10.—Topanga (middle Miocene) paleogeography of Puente Hills region.

non-fossiliferous, and well indurated. Many of its pebbles are slabs of dark, lustrous Pelona schist, which may have come from the northeastern San Gabriel Mountains or from the vicinity of San Bernardino. The absence of Pelona schist fragments from the conglomerates of the Puente that were derived in part from the southeastern San Gabriel Mountains, indicates that the two formations, if contemporaneous, obtained their detritus from different and restricted areas, with a drainage divide roughly following the line of the present middle fork of Lytle Creek.

PALEOGEOGRAPHY

The Topanga (middle Miocene) shore line of Figure 10 is drawn northeast of a locality at the mouth of Dalton Canyon, near Glendora, where Luisian foraminifera were found; northeast of San Dimas, because of middle Miocene (?) mollusks

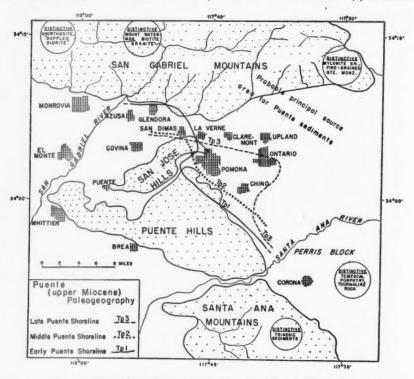


Fig. 11.—Puente (upper Miocene) paleogeography of Puente Hills region.

and echinoids in a sandstone lens in the pyroclastics of Way Hill; then through the Buzzard Peak conglomerate, because that member of the Topanga may be in part or even wholly continental; and continued as a questioned line southwest of Pomona, because the Topanga pinches out somewhere between the thick sequence of the Diamond Bar well (Fig. 2, C3) and the outcrop unconformity between Puente and basement rocks.

The Glendora volcanic field of middle Miocene age is shown chiefly in the marine area of Figure 10. The pyroclastic materials are at least in part marine, as indicated by the associated marine invertebrates at several widely separated localities, including The Texas Company's Covina Community well 27-1. The

tuff breccias of the Glendora volcanics closely resemble, however, subaerial nuées ardentes deposits. It is therefore probable that during parts of Topanga time subaerial volcanoes erupted in this region. The volcanoes were possibly islands in the vicinity of Covina, but as they grew became land-tied peninsulas.

In Figure 11 a progressive overlap of the upper Miocene Puente sediments is indicated. The late Puente shore line is given a Pomona-Chino-Ontario embayment, based in part on the fine grain of the upper Puente sediments which crop out nearest to Ontario and Chino, as contrasted with the coarseness of their correlatives a few miles northwest or southeast, and in part on the actual preservation of some upper Puente sediments of this embayment in the Chino trough or basin, beneath a Quaternary cover.

SUMMARY OF CONCLUSIONS

The study of the Miocene conglomerates of the Puente and San Jose Hills supports the view that they were deposited by streams and currents which brought in pebbles and boulders centripetally from surrounding highlands which formed an arc of approximately 120°, from north-northwest of the western hills to east of the southeastern hills. Probably the greater part of the sediments came from the central part of this arc; that is, from the north and northeast, where now there are the southeastern San Gabriel Mountains and the adjacent Ontario plain. The area of erosion was at least locally rugged, perhaps especially so in middle and early upper Miocene time.

Because the conglomerate samples that have been studied are few and small, and because the source areas are incompletely known, conclusions are necessarily more or less tentative. Further study might be concentrated to advantage on the middle member of the Puente formation with the sandstone given as much attention as the conglomerate. Such work might, for example, solve the problem of the rarity of hornblende in the larger clasts.

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GRAMP'S FIELD, ARCHULETA COUNTY, COLORADO1

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ABSTRACT

Gramp's field, in Archuleta County, Colorado, was discovered in 1935, and until now practically no information pertaining to the field has been released for publication. This article sets forth not only details regarding the geology of the field, but also gives data pertaining to operations and production from the drilling of the first well to the close of the operating season in January, 1945. The oil is being produced from the Dakota sandstone (Upper Cretaceous) in which it has accumulated against an east-west fault crossing a north-south anticlinal axis. The average thickness of the producing part of the Dakota sandstone is 152 feet. All the producing wells are at an elevation of more than 8,000 feet and their average depth is 1,250 feet. The producing area of Gramp's field is 127 acres, and the total production from April, 1937, when installation of storage and pipeline facilities was completed, to January, 1945, has been 2,124,202 barrels. Because of severe winters it is usually necessary to stop field operations from the beginning of January until the middle of April. Gramp's field is unique in that it is privately owned and consequently is free from many State and Federal operating regulations.

LOCATION

Gramp's oil field is in the southeast part of Archuleta County, Colorado, approximately midway between Pagosa Springs, Colorado, and Chama, New Mexico. It is about 6 miles north of the Colorado-New Mexico boundary, on the extreme northeast edge of the San Juan Basin. All the producing wells are on the east side of the Navajo River, which flows approximately along the west boundary of that part of the Tierra Amarilla Grant known as the Banded Peak portion, which lies in Colorado. The location of Gramp's oil field is shown in Figures 1 and 3.

HISTORY

From the beginning, Gramp's field has aroused interest and conjecture because, until publication of this paper, no detailed information has been made public on the geology and operation of the field. The first and only previously published article pertaining to Gramp's field was written by Tolbert R. Ingram³ in 1937. Ingram's article is very general and gives few details. However, the first part, here quoted, brings out some interesting facts about the ownership and the unusual and rapid development of the field during the first 2 years of its operation.

A "mystery" well, generally a wildcat about which the driller withholds all information from the public and other oil men until he has availed himself of all the benefits to be derived from advance knowledge gained by his own exploratory work, is not an uncommon occurrence in the oil business. It is good practice and is recognized as such, but if the test

¹ Manuscript received, December 7, 1945.

² Argo Oil Corporation. The writer expresses thanks to Lafayette M. Hughes for granting permission to publish this paper, and to Ronald K. DeFord for helpful criticism of the manuscript.

² Tolbert R. Ingram, "Colorado's 'Mystery' Field," Mines Magazine, Vol. 27, No. 5 (May, 1937), pp. 32, 33.

is an important one or rumors circulate that a discovery has been or is about to be made, it requires more than ordinary skill in planning to hide the facts from prying eyes. Almost any old-time oil man can spin yarns by the hour detailing methods used in ferreting out information which the wildcatter is trying to keep to himself. It is seldom that more than one or two wells are drilled in any particular area before the land men and geologists have

enough facts upon which to base elaborate reports.

An exception to this rule occurred in Colorado in 1935 and 1936 when a single operator turned the tables by developing a "mystery" field. A discovery was made, the outlines of the probable productive area of the pool were determined by the drill, the wells were electrically equipped for pumping, tankage was erected, a pipe line for transporting the crude to a market was built and a contract for the sale of the oil was signed and sealed before anybody outside of the organization had much of an idea of what it was all about. One can almost picture the driller stepping out on the stage, raising the curtain and saying: "Gentlemen, here is a new oil field, fully equipped and ready to produce. Take a look at it."

It is obvious that such an accomplishment could take place only under unusual conditions. These conditions in themselves are of interest. There is a single ownership of all the land. Neither the state nor the federal government has any voice in its development. There are no royalties to be paid. There are no laws or lease agreements requiring the drilling of offset wells. The operator may drill when and where he chooses and every barrel of oil

belongs to the estate.

The presence of oil along the course of the Navajo River was first mentioned by Arthur Lakes when, in 1901, his report on the probabilities of oil in the region between Pagosa Springs, Colorado, and the San Juan River appeared in the Pagosa Springs Sun. In this report Lakes describes the oil spring near Price Ranch (Fig. 3), approximately 3 miles south of Gramp's field, as follows.

The highest oil spring in the geological formation occurs on Navajo Creek two or three miles west of the Navajo River Basin, a short distance above Price's ranch. The oil comes out from beneath sandstones and sandy shales at the base of the Navajo sandstone and on top of the lower series of shales. It seeps out on the south bank of the river close to the water on Tierra Amarilla land...⁵

Lakes gave no details of the geological structure in the vicinity of the oil spring except to state that the spring "occurs on the upper side of a synclinal basin." This is between the southern nose of the anticline formerly referred to as Price anticline, on which Gramp's field is situated, and the northeast flank of the Chromo anticline.

The oil spring apparently aroused the interest of oil operators. Several shallow wells were drilled to the Dakota sandstone on the Chromo anticline, a large, well developed structure about 5 miles southwest from the spring. These obtained only sulphur water with slight showings of oil. Later, a well drilled about one mile south from the oil spring obtained a small amount of gas in the Mesaverde sandstone (Fig. 3). This well is still capable of producing some gas.

⁴ Arthur Lakes, "Report of the Oil Fields of Archuleta County, Colorado," Pagosa Springs Sun, Pagosa Springs, Colorado, May 27, 1901.

⁵ This quotation was obtained from a copy of Lakes' report. The Navajo sandstone is now referred to as Mesaverde. Lakes' Navajo River Basin is, in all probability, the Chromo Anticline; therefore the "west" in this quotation must be the "east."

In 1933 or 1934, Charles B. Garnett (Fig. 2) promoted and drilled a well on the west side of the Navajo River about one mile south of Peterson Ranch, and obtained a small amount of oil above, and much water in, the Dakota sandstone. Before this well was completed and abandoned, Lafayette M. Hughes, on July 3, 1935, spudded his well No. 1. The location of No. 1 (Fig. 2) is near the south line of Peterson Ranch. It was one of three locations selected by W. A. Waldschmidt who had been engaged to review available information, which included a reconnaissance and generalized structure map prepared by Charles M. Rath of Denver, and a general map prepared by C. T. Dantziger, of Pagosa Springs, Colorado. The other two locations were spotted east of the Navajo River on the Tierra Amarilla Grant but were not drilled because of subsequent developments. By August 20, 1935, well No. 1 had been drilled to 1,447 feet, at which depth the bit had penetrated 2 feet into the Morrison formation. The Dakota formation, 1,235-1,445 feet, contained fresh hot water (101° F.) and only a few showings of oil; consequently, the well was plugged and abandoned.

At the time of completion of well No. 1, Hughes requested Waldschmidt and L. S. Robbins to make a further geological study in the area, and on the basis of scanty, scattered information, obtained by plane-table survey, well No. 2 was located. It was spudded on September 6, 1935, and completed as the discovery well on December 3, 1935. This well (Fig. 2) is on the Tierra Amarilla Grant east of the Navajo River.

Since the completion of well No. 2, the entire structure of the field has been worked out from subsurface information. It was necessary to drill several wells primarily to obtain geological data, because lava flows, valley fill up to 600 feet thick, land slides, minor slumping, and timber and undergrowth make it virtually impossible to obtain surface geological information that can be used in preparing an accurate structural map.

At the close of 1944, twenty-three wells had been drilled. Of these Nos. 1, 4, 8, 9, 11, 12, and 14 were not producers.

PHYSIOGRAPHY

The terrain in the region of the Gramp's field is exceedingly rugged. The Navajo River, which heads near the Continental Divide about 11 miles north of Gramp's field, flows southward through a narrow valley for 15 miles and then turns sharply toward the west. At Gramp's field the floor of this valley is approximately 8,000 feet in elevation. On the west side of the valley the Chalk Mountains rise to heights of 11,000 and 12,000 feet, and on the east side of the valley the southern part of the San Juan Mountains, along the Continental Divide, reaches similar heights. The distance between the crest of the Chalk Mountains and the crest of the Continental Divide is approximately 6 miles, whereas the floor of the valley at Gramp's field, about midway between the two high ranges, is from $\frac{1}{4}$ to $\frac{1}{2}$ mile in width.

⁶ Fee land owned by the Annie Clifton Hughes Estate and adjacent to the west boundary of Tierra Amarilla Grant.

Many tributary streams flowing into the Navajo River, north of Gramp's field, have eroded precipitously walled canyons into the nearly horizontally bedded lava flows which cover much of the region.

Three of the highest peaks of the southern San Juan Mountains are less than 4 miles from Gramp's field. These are Navajo Peak (elevation 11,330 feet) at the south end of the Chalk Mountains, and Banded Peak (elevation, 12,760 feet) and Chama Peak (elevation 11,000 feet) on the Continental Divide (Fig. 3).

STRATIGRAPHY

Both igneous and sedimentary rocks crop out in the Navajo River Valley, near Gramp's field. The sedimentary rocks (Dakota through part of the Lewis) are Upper Cretaceous in age. These are overlain by extrusive igneous rocks (Tertiary), and, along the course of the river, by glacial and stream gravels (Quaternary and Recent).

In Gramp's field the drill has penetrated till and gravel as well as Upper

Cretaceous (Lewis to Dakota) and Jurassic (Morrison) strata.

TABULAR SECTION

Quaternary and Recent		
Tertiary	Till (Wisconsin stage) Hinsdale formation	
	Lewis shale	
	Mesaverde sandstone Niobrara formation	
Upper Cretaceous	Carlile shale	"Mancos"
	Greenhorn limestone Graneros shale	
	Dakota sandstone	
Jurassic	Morrison formation	

JURASSIC

Morrison.—The Morrison formation consists of light, varicolored shales, and buff-colored sandstones. Shades of red are predominant. Shades of green and lavender are common. At the close of the 1944–1945 operating season, the entire Morrison formation had not been penetrated by any well in Gramp's field, but it was reached in Nos. 1, 10, 11, 13, 15, 16, and 17.

UPPER CRETACEOUS

Dakota.—The Dakota formation consists of gray sandstones and dark gray shales. Its average thickness is 210 feet. The upper 40 feet of the Dakota consists of compact dark gray sandy shale and sand. In this interval most of the sand grains are small and angular. The remaining 170 feet consists of sandstones separated by a few thin dark gray-shale beds. In this interval the sand grains are round, subround, and angular. Much of this angularity of grains has resulted from the formation of partially and wholly developed secondary quartz crystals.

Graneros.—Overlying the Dakota are 40 to 50 feet of black, laminated shales containing minor amounts of pyrite, and 100 feet of dark gray, slightly calcareous shales with few Foraminifera, which can be considered to be Graneros. Litho-

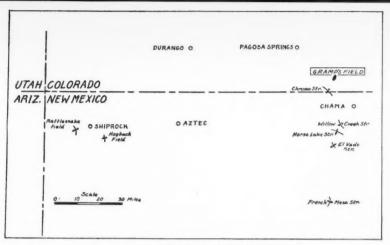


Fig. 1.—Key map showing location of Gramp's field.

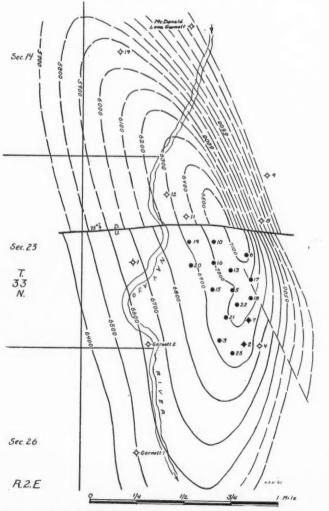


Fig. 2.—Structure of Gramp's field, Archuleta County, Colorado. Structure contours on top of Dakota "pay"; interval, 100 feet.

Fig. 3.—Reproduction of southeast quarter of U. S. Geological Survey, Summitville Quadrangle, Colorado, showing location of Gramp's field, approximate position of 4-inch pipe, Price Ranch, and oil spring and gas well near Price Ranch.



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Fig. 4.—Aerial photograph looking east across Gramp's field, Archuleta County, Colorado. Navajo River, in lower foreground—direction of flow left to right. Average elevation of Navajo River, 8,000 feet. Elevation of Continental Divide, approximately 11,200 feet. Headache Creek forms valley extending from low part of Continental Divide (top center) around left of central untimbered mountain, and past wells 5 and 6 and Camp. Timbered basin area, top right center, in upper nates.



Fig. 5.—Aerial photograph looking southwest from Gramp's field toward Chromo anticline. South end of Gramp's field in right foreground. Mancos shale capped with Mesaverde sandstone forms prominent mesa-like feature extending from right to left near upper part of photograph. These beds form southwest flank of Chromo anticline. Location of wells and other points can be found at intersection of like-numbered or named coordinates.

logically, the 40- to 50-foot black shale interval is similar to the lower Graneros of eastern Colorado and to the Mowry of Wyoming.

Greenhorn.—Approximately 150 feet above the Dakota is a brownish limestone and gray calcareous shale interval from 10 to 20 feet thick which is considered to be Greenhorn. This interval is difficult to determine in well samples because the calcareous shale is similar in color to the Niobrara shales, and because the limestone is not especially well developed. Numerous Foraminifera and Inoceramus prisms are present in both the shale and limestone. Some of the limestone is made up entirely of Inoceramus shell fragments.

Carlile.—Overlying the Greenhorn is gray calcareous shale with an average thickness of 120 feet. Some Foraminifera and *Inoceramus* prisms are present. This shale member and the overlying sandstone member together compose the Carlile formation.

The sandstone member, the so-called "Carlile sandstone," is about 40 feet thick in Gramp's field. It is a fine-grained, clayey sand in which the grains are small and angular. Grains of glauconite, and small, amber-colored, tapered *Inoceramus* prisms are characteristic of this member. Because it is very clayey, the "Carlile sandstone" is ordinarily not recognized by the drillers, and for the same reason it is commonly difficult to recognize in outcrops.

Niobrara.—The Niobrara formation consists primarily of calcareous, dark gray shales that occupy the interval between the Mesaverde sandstone and the Carlile shale. In Gramp's field the complete Niobrara section was penetrated only in well No. 14. It was also penetrated completely in the Cortez Oil Company's well in the NE. ½ Sec. 2, T. 32 N., R. 2 E. This well is approximately $2\frac{1}{2}$ miles south of well No. 1.

Throughout most of the Niobrara the shales are moderately well laminated, highly calcareous, and are gray with white or light gray specks. *Inoceramus* prisms and typical Niobrara microfauna (especially *Globigerina* and *Gümbelina* species) are abundant in these shales. The base of the Niobrara or top of the "Carlile sandstone" can be determined readily; however, the top of the Niobrara is a much more difficult point to select.

In well No. 14 gray calcareous shale first appears 115 feet below the bottom sandstone member of the Mesaverde. The first Niobrara Foraminifera occur 150 feet below this sand, and typical speckled gray calcareous Niobrara shales appear 90 feet below the foraminiferal horizon. In the Cortez well, south of Gramp's field, however, the calcareous shales are directly below the lowest member of the Mesaverde sandstone; the first speckled shale is 107 feet below; and the first Foraminifera are 185 feet below. Because of the variation in position of the gray calcareous shale, the calcareous speckled shale, and the Foraminifera-bearing shale zone with respect to the bottom sand member of the Mesaverde sandstone, and even though the gray calcareous shales are slightly gritty to sandy, these shales are considered by the writer to belong in the upper part of the Niobrara. In well No. 14 the Niobrara formation is 1,225 feet thick, whereas in the Cortez well it is only 1,147 feet thick.

Mesaverde.—The Mesaverde formation has an average thickness of approximately 750 feet and consists of fine-grained gray sandstones with interbedded gray sandy shales. The top of the Mesaverde sandstone is relatively easy to determine but the selection of the base is difficult because of interbedding of thin layers of sandstone and sandy shales. The upper, massive sandstones are non-calcareous; the middle and lower sandstones and sandy shales are slightly calcareous. In subsurface samples, the Mesaverde contains a considerable amount of pyrite. Well No. 8 was the only well in Gramp's field which penetrated the entire Mesaverde section. In this well the Mesaverde is 920 feet thick. This thickness is in excess of the normal thickness because the well was drilled on steeply dipping beds. Minor faulting also may have caused some lengthening of the Mesaverde section in well No. 8.

Lewis.—The Lewis formation is made up of dark gray shales which are slightly sandy, or gritty, and, in places, slightly limy. These shales can be recognized easily, and there is seldom any chance for them to be confused with the calcareous shales of the Niobrara formation. Outcropping Lewis shale in the Gramp's field area contains a baculite species with a highly iridescent calcareous shell. Well No. 8 penetrated 580 feet of Lewis in which a few iridescent shell fragments, probably from a baculite species, were observed. At some outcrops near, but not in the immediate vicinity of Gramp's field, the Lewis contains large calcareous concretions. No attempt was made to measure the thickness of the Lewis; the thickness given by Dane and Bryson is 2,000 ± feet.

TERTIARY

Hinsdale.—The volcanic rocks of this area are interbedded flows and pyroclastic beds of the Hinsdale formation. They cover the high mountain ranges north, east, and west of Gramp's field and reach the Navajo River bed near East Fork, approximately 4 miles north of Gramp's field.

QUATERNARY AND RECENT

Till and gravel.—The Navajo River valley is filled with till and gravel, most of which has been derived from the igneous extrusives which surround the entire valley. Because it is not possible to distinguish in well cuttings between these two types of materials, they are considered here as one unit. Wells 1, 11, and 20, which were drilled relatively near the Navajo River, penetrated respectively 525, 620, and 555 feet of till and gravel. Nearly all the grains in the samples are of igneous material. Some rounded quartz grains and some clay are present. Well No. 4, near the abrupt rise of the mountains on the east side of the valley, encountered no gravel, but wells 8 and 9 (respectively 384 and 426 feet higher in elevation than well No. 4) drilled through 201 and 280 feet of gravel similar to that encountered in the wells near the river.

⁷ C. H. Dane and R. P. Bryson, "Preliminary Map Showing Geologic Structure of Part of Rio Arriba County, New Mexico," U. S. Geol. Survey (1938). Scale: 1 inch equals 1 mile.

According to Atwood and Mather⁸ the till in the Navajo River valley, in and north of Gramp's field, is Wisconsin till. The southernmost point of this till, as mapped by them, is nearly due east of Navajo Peak. The remainder of the material, which the writer has called till and gravel, is mapped by Atwood and Mather as modern alluvium. Wells drilled in Gramp's field have found till and gravel resting on the Lewis, the Mesaverde, and the Niobrara.

STRUCTURE

Gramp's field (Fig. 2) is on the crest of an asymmetrical anticline, earlier referred to as Price anticline, in which the dip ranges from 8° to 10° on the west flank and from 30° to 35° on the east flank. The Dakota structural axis, although slightly curved, trends approximately north-south, and lies about $\frac{3}{4}$ mile east of the Navajo River.

The structure of Gramp's field, or the top part of the anticline, contoured on top of the Dakota pay sand, is shown in detail in Figure 2. Although the structure, as shown by this map, appears to be that of a commonplace anticline, it is probably much more faulted than the map indicates, because there is evidence in the well samples that the entire producing area is crossed by many faults of minor or major importance.

A major fault, or narrow fault zone, extending east and west, crosses the highest determined point of the anticline south of wells 8 and 11, and north of wells 6, 10, and 19. The relative downward displacement of the northern part of the anticline with respect to the southern part is estimated to be 600 feet. In addition, present data indicate that the structural axis of the northern part of the anticline has been moved 300-400 feet westward, with respect to the axis of the southern part. Other faults with small displacement undoubtedly occur in other parts of the structure, but only one of these is shown on the structural map of the oil-producing area (Fig. 2).

The first seven wells outlined the southward plunge of an anticline. The Mesaverde sandstone is absent in all these wells except No. 6. The doubtful exception was ignored and it was assumed that the axis of the anticline extended northeastward. On this assumption wells 8 and 9 were drilled. Well No. 8 entered Lewis shale, then penetrated the entire section of Mesaverde, and drilled into the calcareous Niobrara shales before it was shut down. Well No. 9 drilled to only 935 feet, and was discontinued at that depth, because it had not reached the Mesaverde. Drilling operations were then begun nearer the known production and the presence of a fault of considerable displacement was recognized in well 10 in which the "Carlile sandstone" was missing.

In well 11 the elevation of the top of the Carlile proved to be 711 feet lower than in well 6. This was the first direct evidence as to the magnitude of the faulting. Furthermore, well 11 crossed a fault; for the bit drilled only 18 feet of

⁸ Wallace W. Atwood and Kirtley F. Mather, "Physiography and Quaternary Geology of the San Juan Mountains, Colorado," U. S. Geol. Survey Prof. Paper 166 (1932), Pl. 1.

Dakota sandstone before entering Morrison shale. Well 6 had found 110 feet of sandstone, presumably Mesaverde, between the base of the gravel and the calcareous Niobrara shales. If this sandstone is Mesaverde, approximately 615 feet of Niobrara is missing and the contact of the Mesaverde with the Niobrara

shale establishes another point on the east-west fault.

Faulting is indicated in outcrops along Headache Creek which flows southwestward between wells 5 and 6 and 17. The course of this stream shows clearly on Figure 4. Niobrara shales crop out in the stream bed near well No. 5 and Lewis shales crop out farther upstream below well No. 6. Mesaverde sandstone was not observed between wells 5 and 6; therefore, in this area, Lewis and Niobrara must be in contact as the result of faulting of a magnitude similar to that found in the subsurface. About $\frac{1}{4}$ mile east of well No. 4 is a poor outcrop of Mesaverde sandstone, but this can not be traced into Headache Creek.

Well No. 17 encountered the top of Dakota at 1,200 feet, the top of the Dakota pay section at 1,263 feet, and the top of Morrison at 1,285; thus it lacked all but the top 85 feet of Dakota, the rest being cut out by a fault. This well is near the

area where faulting is indicated on the surface.

Various computations were made, using several combinations of points of known faulting in wells, to determine the strike and dip of the faults in Gramp's field. The east-west fault, shown in Figure 2, gives the average strike of the fault on which the points will fit best; however, it is possible by computation to swing the strike more toward the northwest. Until additional points on the fault are determined by drilling, its exact position can not be determined. Furthermore, it is the writer's belief that the direction of the faulting thus far established is representative of a series of faults which combine to make a narrow fault zone. The computations do indicate, however, that the fault that cuts out most of the Dakota in well No. 17 is not the main east-west fault zone.

After the presence of a fault zone had been established, well No. 14 was drilled about one mile northwest of the producing area. It encountered 350 feet of Mesaverde under 312 feet of surface gravel and then drilled a normal section to the Dakota. At the same time, the McDonald-Lena Garnett shallow well was drilled about 2,200 feet east and slightly north of well No. 14. This well reached the top of the Mesaverde about 700 feet lower in elevation than did well No. 14. The McDonald-Lena Garnett well, however, was not drilled to the Dakota.

With the information obtained from the drilling of wells 8, 9, 11, 14, and the Lena Garnett No. 1, it is possible to contour the top of the Dakota pay sand north of the major fault zone but not with any assured accuracy. The excessively long section of Mesaverde drilled in well No. 8, the fact that the Mesaverde had not been reached in well No. 9, and the relative positions of the Mesaverde in well No. 14 and in the Lena Garnett well, all established the east dip. The west dip was established by outcrops of Lewis shale in the side of the valley south and west of well No. 14. Well No. 12 might have given some valuable information to be used as control in contouring the area north of the fault zone, but, unfortu-

nately, it was necessary to abandon this well when the tools were lost in the gravel at a depth of 400 feet.

The position of the closing contour limiting the length and breadth of the anticline has not yet been determined. However, subsurface data, combined with a limited amount of information obtained at Cretaceous outcrops, establishes the

TABLE I
WELL DATA, GRAMP'S FIELD, ARCHULETA COUNTY, COLORADO

Well No.	Eleva- tion (Feet)	Base of Gravel	Top of Carlile	Top of Dakota	Top of Dakota Pay	Top of Morri- son	Total Depth (Feet)	
1	7947	525	925	1235	1285	1445	1447	
2	8115	50	670	1000	1152		1172	
3	8042	225	760	1082	1127	1	1253	
4	8197	0	1010	1353	1407		1412	
5	8117	150	760	1070	1132		1160	
6	8275	115	840	1102	1156		1225	
7 8	8212	190	740	1126	1232		1253	
8	8581	201					2300	Stopped in Up Niobrara
9	8623	280					935	Stopped in Lewis
10	8190	443	Missing	1107	1164	1316	1317	
11	8054	620	1330	1660	Missing	1678	1752	
12	8045						400	Lost in gravel
13	8170	130	799	1075	1131	1303	1303	
14	8180	312	1895	2180	2220		2220	
15	8073	185	775	1065	1114	1269	1269	
16	8116	290	790	1063	1115	1273	1273	
17	8271	55	812	1200	1263	1285	1286	
18	8265	48	768	1170	1225	1400	1400	
19	8020	470	900	1065	1106		1222	
20	8018	555	780	1085	1140		1172	
21	8085	160	705	1035	1098		1120	
22	8115	32	625	955	1050		1058	
23	8069	120	712	1054	1105		1115	
Garnett 1	7951				1454		3	
Garnett 2	7924				1200		3	

general structure of the anticline southward from the east-west fault zone to within about 2 miles of the New Mexico state line.

Table I summarizes some of the pertinent well data which has been used in determining the structure of Gramp's field.

RESERVOIR ROCKS

All the oil being produced in Gramp's field is from the Dakota formation. Shown in Figure 6 is a graphic log of the Dakota section drilled in well No. 10, which will be used as a basis for discussion because it is representative of the Dakota throughout the field. The total thickness of the Dakota in well No. 10 is 209 feet, of which the lower 152 feet is the main producing interval.

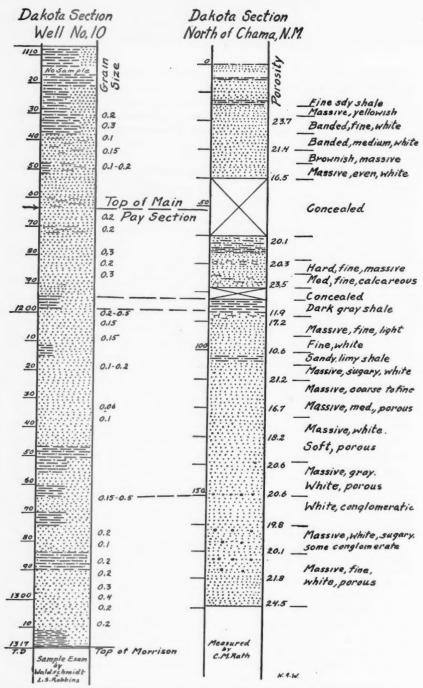


Fig. 6.—Comparison of the Dakota formation drilled in well No. 10 with a Dakota section measured at an outcrop north of Chama, New Mexico.

The upper 57 feet of the Dakota consists of compact gray shaly sands and sandy shales. This interval has had some good showings of oil in the field wells, but it probably can not be considered to be a pay zone. The first good production is obtained immediately below the sandy shale and shaly sandstone member from a sandstone 30 feet thick. This sandstone is made up of relatively uniform grains (0.2 to 0.3 mm. in diameter), and contains an abundance of secondary quartz crystals, which are partially or wholly developed. The next 5 feet of sandstone contains an appreciable amount of dark gray shale. The sand grains in the underlying 48 feet are angular to subround, partially cemented, and range from 0.06 to 0.5 mm. in diameter. A small amount of dark gray shaly sand appears near the middle of this interval. The next 43-foot interval consists of sandstone and sandy shales. The most prominent of the shales are at the top and bottom of the interval. Two other shale breaks occur near the middle. The grains range in size from 0.15 to 0.50 mm. The bottom 26 feet of Dakota consists of sand grains similar to those in the top 30 feet of the producing section.

Cores of Dakota sandstone were not obtained from this well; therefore, it was not possible to determine the porosity. The porosities of outcrop samples collected by Charles M. Rath from a measured section of Dakota north of Chama, New Mexico, were determined by Melcher's method. As Rath's section may be correlated moderately well with the section drilled in well No. 10 (Fig. 6), the porosities of the outcrop samples are assumed to be representative of the porosity of the Dakota in well No. 10. The range in porosities within the six intervals just described is as follows.

Thickness	Percentage Ra	nge of Porosity	Average Percentage
o- 57 feet	10.3	23.6	16.9 (13 samples)
57- 87 feet	Not det	23.5	19.6 (6 samples)
87- 92 feet	Not det	ermined	
92-140 feet	3.9	22.4	14.1 (13 samples)
140-183 feet	19.8	21.8	20.5 (4 samples)
183-209 feet	24.5		24.5 (1 sample)

In well No. 10 two shaly intervals, approximately in the middle of the Dakota formation, are correlated with shale breaks shown in Rath's section (Fig. 6); however, the lower 69 feet of the Dakota in well No. 10 contains more shale than does the section measured by Rath.

Because difficulties have been encountered in attempting to shut off water in several of the wells in Gramp's field, it is assumed that the shale breaks in the Dakota are local shale lenses, not well defined extensive beds. It becomes necessary, therefore, to consider all the producing Dakota sandstone as a single unit.

RELATION OF ACCUMULATION TO STRUCTURE

All the proved oil in Gramp's field has accumulated in a small part of the crest of the anticline adjacent to and on the south or upthrown side of the major east-west fault or fault zone. No oil has been encountered in the wells drilled thus

far on the north or downthrown side of the fault. Until additional wells are drilled along a possible axis trend on this side, it must be construed that the accumulation of the oil in Gramp's field occurred after the major faulting. The upthrown part of the anticline is therefore closed on the north by the major fault or fault zone. On the basis of such construction, it is necessary to assume that the oil reached the area of accumulation (the Dakota sandstone reservoir) by migration. Otherwise, if it is assumed that the oil was formed in place and that the faulting was post accumulation, the same type of oil would be present on the downthrown side of the fault. Drilling of wells along the projected axis trend (Fig. 2) between wells 8 and 9 and wells 11 and 12 would prove the absence or presence of oil on the downthrown side. This projected axis has not been drilled because the highest part of the Dakota on the downthrown side is approximately 300 feet lower in elevation than it is in the lowest producing well on the upthrown side. Furthermore, previous interpretations of the structure north of the fault showed that the axis was moved farther west by faulting than indicated in Figure 2.

If the accumulation is post-faulting, the oil must have come from the south. Yet the other structures south of Gramp's field are barren. The Dakota sandstone in the Chromo anticline about seven miles southwest contains sulphur water with only very slight showings of oil. Fresh water occurs in the Dakota sandstone in Dulce structure 18 miles southwest of Gramp's field, and in the Dakota sandstone in the Azotea structure southeast of Gramp's field. There is no indication of oil in the Dakota sandstone outcrops on the flanks of the North and South El Vado domes, about 30 miles south of Gramp's field, nor in the outcrops north of Chama, New Mexico, along the Chama River. Nevertheless, the oil necessarily came from the area south of the fault, if it migrated after the faulting took place.

It is probably most reasonable to assume that the oil originated from the organic materials within the Cretaceous shales, entered the permeable and porous Dakota sandstone, and reached the area of accumulation in Gramp's field during

the later stages of migration.

Faulting has undoubtedly aided considerably in the accumulation of oil in Gramp's field. This is indicated by the showings of oil that are encountered during drilling ordinarily where white calcite and slickensided shale particles are found. The presence of calcite suggests that during the early stages of accumulation the carbonate-bearing waters found their way into, through, and out of fractures in the area of pressure relief at the crest of the anticline, and precipitated their carbonate as calcite in the fractures. The expulsion of water from the fractures may have taken place during the time of fluid migration through the Dakota sandstone, the water probably moving toward the fractures at a greater rate than the oil. If so, the oil in the Dakota had time to coagulate and migrate toward the area of accumulation where it was trapped because the fractures had been filled by the precipitated calcite. Oil also seeped into the fractures in sufficient quantity to be observed as showings during drilling. It should probably be as-

sumed also that some fracturing occurred after the period of accumulation.

The Dakota oils in the Rattlesnake and Hogback fields on the northwest edge of the San Juan Basin are different from the oil in Gramp's field. The differences in the oils are probably due to manner and time of accumulation. The outstanding differences in gravity, pour point, Saybolt viscosity, and the distillation products are shown in Table II.

The Dakota sandstone is at a relatively shallow depth in all three fields. At Rattlesnake the discovery well was completed at 826 feet for ten barrels per day. Well No. 5, in Rattlesnake, was drilled to 758 feet for its first production, and then deepened to 839 feet at which depth the rate of production was increased from 300 barrels to 1,500 barrels per day. The depth to the Dakota sandstone in

TABLE II ANALYSES OF CRUDE OILS FROM DAKOTA SAND

	Gramp's Field1	Rattlesnake Field ²	Hogback Field ³
Gravity	31.6° A.P.I.	59.5° A.P.I.	60.0° A.P.I.
Pour point	60°F.	Below 5°F.	Below 5°F.
Color	Brownish black	Green	Green
Base	Intermediate Paraffin	Paraffin	Paraffin
Sulphur	0.38%	Less than o. 1%	Less than o. 1%
Saybolt viscosity at 100°F. By distillation	77 Sec.	30 Sec.	30 Sec.
Gasoline and naphtha	14.82	75.2	74.5
Kerosene	9.18	13.8	13.3
Gas oil	17.75	4.5	6.0
Non-viscous lub. distillate Medium lub. distillate	14.50 8.39	3.6	4.4
Residuum	34.20	0.9	1.7
Distillation loss	1.16	2.0	0.1
Total	100.00	100.0	100.0

p. 122. * *Ibid.*, pp. 107-08.

the Hogback field varies from 647 to 988 feet. In the producing wells of Gramp's field the depth to the Dakota sandstone, exclusive of the gravel, ranges from 530 to 1,145 feet. Because the oil in Gramp's field is within 530 feet of an old Cretaceous surface beneath till and gravel, in an area of faulting and fracturing, it is possible that the gas and the light constituents of the oil escaped through the fractures. The loss of the light fractions may account for the differences in composition between Gramp's oil and the Rattlesnake and Hogback oils. It is true that the depth to the Dakota in Rattlesnake and Hogback is also shallow, but in all probability the faulting and fracturing in these fields is not so great as in Gramp's field. This conclusion is based on the following statements.9 In the Hogback field: "A single fault has been mapped. This is shown in the canyon wall near the No. 1 well, where a small displacement is visible in the Tocito sand." In the Rattlesnake field: "Only minor faulting is present."

Archuleta County, Colorado. Analyst, Robt. A. Baxter.
 "San Juan County, New Mexico, Oil and Gas Resources of New Mexico," New Mexico School of Mines Bull. 18 (1942),

[&]quot;The Oil and Gas Resources of New Mexico," New Mexico School of Mines Bull. 18 (1942), pp. 107, 119.

There is no gas, except showings, in the Dakota sand in Gramp's field or in the Hogback field. All Gramp's wells are on the pump. Hogback wells flow on account of a water drive. Originally sufficient gas occurred with the Rattlesnake oil to cause the wells to flow.

The movement of oil through faults in Gramp's field is definitely proved in well No. 19. During the drilling of this well oil in commercial quantities was encountered at a depth of 1,005 feet, approximatly midway between the base of the Carlile and the top of the Dakota sandstone. Water was found with the oil in the lower part of the Dakota. When effort was made to shut off this water by cementing, all the main Dakota pay section was shut off. The well has, nevertheless, continued to be a good producer, all the oil coming through the fault at a depth of 1,005 feet. The history of the production of this well is shown on Figure 8. Since plugging off, well No. 19 has not made an appreciable amount of water at any time up to the close of the producing season in January, 1945. The oil is similar to the oil from the other wells in the field. Therefore, it must be assumed that the oil is coming from the Dakota sandstone and is migrating into the well along the fault. It has not yet been possible to determine where this fault enters the Dakota sandstone.

Some have postulated that the source of the oil in Gramp's field is from formations older than the Dakota, and that it has reached its present area of accumulation by migration along fault planes. This seems improbable for the following reasons: (1) wells drilled on the Chromo anticline which is the nearest to Gramp's field encountered water in the Morrison and the Wingate sands which underlie the Dakota; (2) between the Wingate and the Pennsylvanian there are no producing sands in the San Juan Basin area; (3) the Pennsylvanian, which is productive in Rattlesnake field, may not even be present beneath Gramp's field; for it is absent in the wells drilled on the Chromo, Horse Lake, and El Vado structures, and it does not appear in outcrops southeast of Chama, New Mexico. The nearest well to Gramp's field in which the Pennsylvanian rocks were encountered was drilled on French Mesa, about 50 miles south.

DRILLING AND OPERATING METHODS

Fort Worth spudders, one Model D and one Model Super J, were used for drilling of all wells in Gramp's field. During the early development of this field, both these rigs were in operation 24 hours a day. The average time for completion of a well was 30 days.

Inasmuch as the size of the casing used for drilling these wells and for putting them on production has varied, the casing records of wells 5 and 10 are here given as representative of the casing program for the entire field.

WELL NO. 5-TOTAL DEPTH 1,160 FEET

123-inch: 118 feet (30 feet above base of gravel; all but 38 feet recovered)

10-inch: 513 feet (recovered) 8½-inch: 969 feet (cemented)

6%-inch: 204 feet (956-1,160 feet: perforated liner)

WELL NO. 10-TOTAL DEPTH 1,317 FEET

12½-inch: 115 feet (recovered) 10-inch: 257 feet (recovered) 6½-inch: 1,118 feet (cemented)

In some wells $15\frac{1}{2}$ -inch casing has been used as a starting string primarily to assure a hole large enough to permit drilling through the gravel. When drilling the gravel it has always been necessary to drive the casing after drilling each few feet in order to prevent the gravel from caving around the drilling tools. Well No. 12 was lost in the gravel because this procedure was not followed.

There are no flowing wells in Gramp's field. Each producing well is equipped with an electrically driven Jensen pump jack. The power for these units is generated at a central plant near the west side of the field. The tubing in the wells is 2 inches in diameter and the rods \(\frac{3}{4}\) inch. All flow lines from the wells are connected to a gunbarrel which discharges into a central storage tank of 20,000 barrels capacity. Because of the severe winter weather these flow lines are not only buried but are also heated by steam generated in the boilers at the central power plant. Tretolite is introduced into the flow lines at the wells to aid in separating the water and the oil. This treatment, in conjunction with the gunbarrel separation and additional heating and treating in the central tank, results in a nearly complete removal of water before the oil enters the pipeline.

The oil is pumped from the central storage tank through a 4-inch pipeline, $14\frac{1}{2}$ miles long, to Chama, New Mexico, into one 55,000 barrel and two 20,000 barrel storage tanks. The pipeline crosses the Continental Divide at an elevation of 8,709 feet, approximately 3 miles south of the pump station. The low point of the pipeline, near the Navajo River, on the west side of the Continental Divide, is 7,876 feet. From the central power plant the drop in the pipeline grade is 149 feet. From the low point to the top of the Continental Divide the lift is 833 feet. From the high point on the Divide, the pipeline follows the course of the Chamita River to Chama. The line is buried over its full course except over small draws and gulches where it is bridged and insulated.

From Chama the oil is shipped in narrow-gauge tank cars to the Oriental Refinery at Alamosa, Colorado. This refinery was built by Lafayette M. Hughes. Previous to its construction, and in the first year of its operation, part of the oil was transferred at Alamosa from the narrow-gauge tank cars to standard-gauge tank cars and shipped to the Continental Refinery in Denver, Colorado.

PRODUCTION

The producing area of Gramp's field is 127 acres. The total production from 1937 through January, 1945, has been 2,124,202 barrels. The calculated yearly production of the individual wells is given in Table III. The history of the production of several wells is shown graphically by the percentage fluid production curves on Figures 7 and 8. The curves illustrated have been selected because each shows certain interesting characteristics. These curves show the increase in water

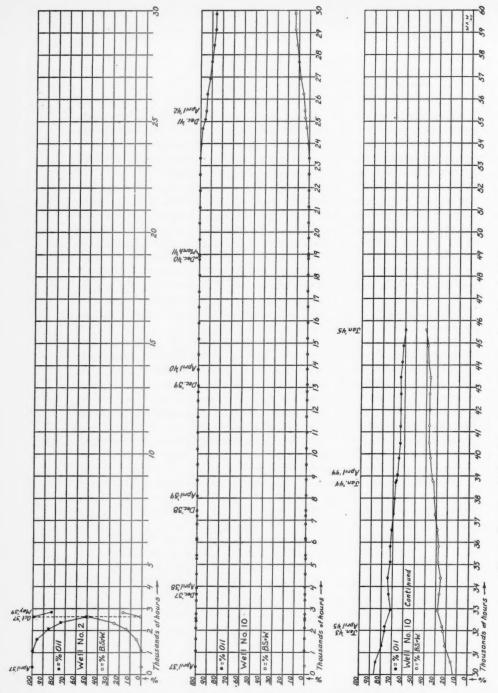


Fig. 7. -- Percentage fluid production curves of wells 2 and 10, Gramp's field, Archuleta County, Colorado.

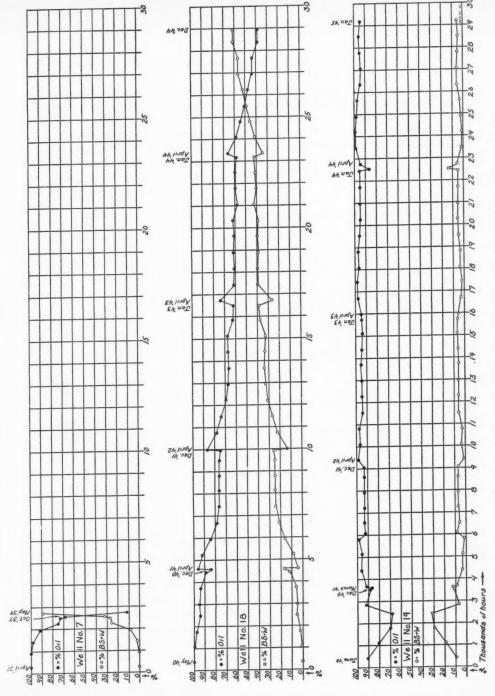


Fig. 8.-Percentage fluid production curves of wells 7, 18, and 19, Gramp's field, Archuleta County, Colorado.

and the decrease in oil on a percentage basis over periods measured in thousands of hours of operation.

The percentage curves of well No. 2 (Fig. 7) show 100 per cent oil production during the first 2 months of its operation, and an accelerated decline in the percentage of oil produced during the next 4 months. After a short shut-down period the well was again put on production in October, 1937, but only 168 barrels of oil were produced with no water. The well was deepened in 1938 from 1,121 to 1,172 feet but did not produce again until May, 1939, at which time the percentage of oil again dropped rapidly at approximately the same rate as in the early months

TABLE III

BARRELS OF OIL PRODUCED BY WELLS FROM 1937 THROUGH JANUARY, 1945. GRAMP'S FIELD,
ARCHULETA COUNTY, COLORADO

Well No.	Year 1937	Year 1938	Year 1939	Year 1940	Year 1941	Year 1942	Year 1943	Year 1944*	Total Barrel. through Jan., 1945
2	21,751	_	1,537	_	_	_	_	_	23,288
3	36,942	36,983	18,321	9,665	2,246	9,954	7,536	7,853	129,500
3 5 6	32,647	35,035	52,662	41,353	43,380	33,855	23,336	13,478	275,746
6	35,315	36,907	50,197	36,509	39,304	33,476	30,039	25,422	287,169
7	21,540	_	211	_	_	_	-	_	21,751
10	34,130	35,370	53,951	48,632	62,241	51,610	48,268	35,086	369,288
13	35,212	39,456	51,679	36,361	37,052	37,146	34,800	24,989	296,695
15			32,623	49,159	57,216	48,154	40,807	23,381	251,340
16	_	_	18,471	42,452	30,188	15,712	8,260	7,123	122,206
17	-		-	2,576	2,669	3,913	5,025	7,155	21,338
18	_	-	-	34,467	16,252	11,739	22,946	23,237	108,641
10	-		_	22,896	23,527	16,946	24,106	53,772	141,247
20	-	-	-	I,III	9,912	11,225	6,795	4,225	33,268
21	-		_	_	_		_	15,810	15,810
22	-	_	-	-		_	_	22,875	22,875
23		_	_					4,040	4,040
	217,537	183,751	279,652	325,181	323,987	273,730	251,918	268,446	2,124,202

^{*} Includes month of January, 1945.

of operation. Because this was considered to be a poor well that would produce a small percentage of oil and a large percentage of water, it was abandoned but not plugged.

The percentage curves for well No. 7 (Fig. 8) also indicate a rate of accelerated decrease in percentage of oil and a corresponding increase in percentage of water during the short period of the well's operation. An effort was made to shut off part of the water in this well, but during these operations a spear was lost while attempting to pull the $6\frac{5}{8}$ -inch liner, and the well was abandoned. The curves for well No. 7 are similar to those of well No. 2, especially in regard to the accelerated drop in the percentage of oil after water first made its appearance.

The curves for well No. 10, which has been the best producer in the field, are shown in Figure 7. From April, 1937, until October, 1941, this well produced nearly 100 per cent oil. During November and December, 1941, the percentage of oil

began to decrease appreciably, at which time it was thought that the decrease might be at an accelerated rate as it had been in wells 2 and 7. However, on continued production, the decrease in percentage of oil was at a moderate rate from April, 1942, to January, 1945. In contrast with the other wells in the field, well No. 10 does not show a marked increase in the percentage of oil after a shutdown period.

The curves for well No. 18 (Fig. 8) show the effect on production of the shutdown period in the winter which is usually from January to the middle of April.

	Well Depth	No.6 1225	Well Depth		Well No. 14 Depth 2257		
	Na+K Scare 76	Co. Mg Solunia gr./Liker Co. s HCO.		CarMy Saimty gr/Liter CO: 5 WCO;	Na 1K	CorMy Salinit gr/lile	
Substance	Parts per Million	Reacting Value	Parts per Million	Reacting Value	Parts per Million	Reacting Value %	
Sodium (Na+K)	1480.7	48.68	560.7	48.06	578.72	48.82	
Calcium (Ca)	23.4	0.88	13.4	1.32	7.40	0.72	
Magnesium (Mg)	7.1	0.44	3.8	0.62	2.90	0.46	
Sulphate (504)	183.4	2.89	382.3	15.69	586.82	22.99	
Chlorine (CI)	380.0	8.10	50.0	2.78	75.75	4.15	
Carbonate (CO3)	215.8	5.44	83.9	5.51	52.71	3.41	
Bicarbonate (HCO3)	2709.0	33.57	805.3	26.02	611.10	19.45	
Silica	22.4		14.8				
Iron and Alumina	0.6		1.6				
Total	5022.4	100.00	1915.8	100.00	1897.40	100.00	
pH value	7.9		7.	8	?		

Fig. g.—Analyses of water from Dakota sandstone, Gramp's field, Archuleta County, Colorado.

These curves were selected primarily because they are representative, in general, of the same irregularities as the field curve which includes the production of all wells. It will be noted that, following each shut-down period, the percentage of oil has increased considerably and that when pumping is resumed there is a rapid decline followed by a gradual decline. The reason for the build-up, or the increase in percentage of oil during each shut-down period, is probably that the oil is being pumped at a rate greater than the flow of oil through the reservoir rock, and that during the shut-down period there is a tendency toward equalization of pressure of oil and water in the reservoir.

The curves for well No. 19 (Fig. 8) illustrate the rapid decrease in percentage of oil and increase in percentage of water during the first 4 months of the well's production (June through September, 1940). The rapid decline in percentage of oil took place while all of the Dakota section in the well was open. Plugging back and testing of well No. 19 was done during October and November, 1940, and the percentage of oil shown as produced after part of the Dakota was plugged off is higher than it was in the previous 4 months. From the beginning of the operating season in March, 1941, until the close of the operating season in January, 1945, the oil in the fluid produced remained at a rather constant average of 95 per cent. The curves of well No. 19, therefore, not only illustrate the rapid encroachment of water during the time that the Dakota section was open, but also the high and rather constant percentage of oil that is entering the well through a fault fissure.

FIELD WATERS

Water is produced with the oil from the Dakota formation in Gramp's field. The analyses of three samples of this water are given in Figure 9. Of these analyses, the one from well No. 6 is selected as being representative of the normal Dakota water in the producing area. The analysis of the water from well No. 17 represents Dakota water in the faulted area on the east side of the field; and that from No. 14, the Dakota water north of the major fault.

The water from well No. 6 is nearly $2\frac{1}{2}$ times as saline as the waters from wells 17 and 14. Well No. 6 has essentially a sodium carbonate water comparable with water from the Dakota formation in many other localities. It is also very low in sulphate. The water from wells 17 and 14 both show a higher sulphate content. In well No. 17 this may be due to contamination with water from the Morrison formation, which was encountered after drilling only a few feet of the Dakota section. It is also possible that the low sulphate content of the water in well No. 6 is the result of sulphate reduction by bacterial action in the presence of oil and that this reduction has not progressed as rapidly in the faulted area of well No. 17 with its short Dakota section, and has not taken place at all in the vicinity of well No. 14.

TECTONIC FRAMEWORK OF NORTHWESTERN SOUTH AMERICA¹

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ABSTRACT

The tectonic framework of northwestern South America suggests two major trends oriented approximately N. 40° E. and N. 30° W. These two trends are continuous over gret distances and cross each other at an angle of about 70°. The trends appear to reflect the orientation of large blocks which are possibly controlled by the law of isostasy and separated from each other by zones of weakness. The major elements of the framework are reflected in the detailed structure of the pliable sediments and consequently have had an indirect but far-reaching effect on the accumulation of oil.

INTRODUCTION

Our rapidly increasing knowledge of the geology of northwestern South America, primarily as the result of the search for oil, has furnished abundant material for an analysis of the tectonics of this part of the world. In the following discussion an attempt is made to analyze the rigid framework of the basement complex of northwestern South America which must have affected the structure of the pliable sedimentary formations.²

GEOGRAPHY

The region selected for this discussion lies between Latitude 12° North and 6° South of the Equator and between Longitude 66° and 82° West of Greenwich. It covers all of Colombia and Ecuador and parts of Panama, Venezuela, Brazil, and Peru.

The dominant physiographic feature of this region (Fig. 1) is the Cordillera de los Andes which extends from Peru, where it trends parallel with the Coast, through Ecuador and Colombia into western Venezuela. In Colombia, the

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² Exploration division, Socony-Vacuum Oil Company, Inc., 26 Broadway. The writer wishes to express his appreciation to E. Jablonski and W. W. Hardy of the Socony-Vacuum Oil Company, Inc., New York, for the helpful criticism and suggestions offered in connection with the preparation of the present paper.

³ The paper is based on approximately two years' field experience in Colombia and on a study of the literature for this part of South America as well as selected literature bearing on the subject of regional tectonics. Applying the principle of H. Stille's "Rahmenfaltung" (folding of poorly consolidated rocks within a framework of highly consolidated rigid masses), the writer observed evidence of two major forces being alternately dominant during Cenozoic time in northwestern South America. Instead of north-south and east-west trending structural axes as referred to by C. Schuchert and called by him Pacific and Caribbean, respectively, the writer found northwest-southeast and northeast-southwest structural trends dominant in the Cenozoic of Colombia. In an effort to find the cause of this structural pattern expressed in the Cenozoic rocks of Colombia the writer has studied the evidence as it is now available in the record of the older rigid masses and in the uplifts which must have been the result of the same forces which were involved in the tectonics of the Cenozoic. The writer's interpretation of the evidence and his conclusions regarding the framework are presented in the present paper.

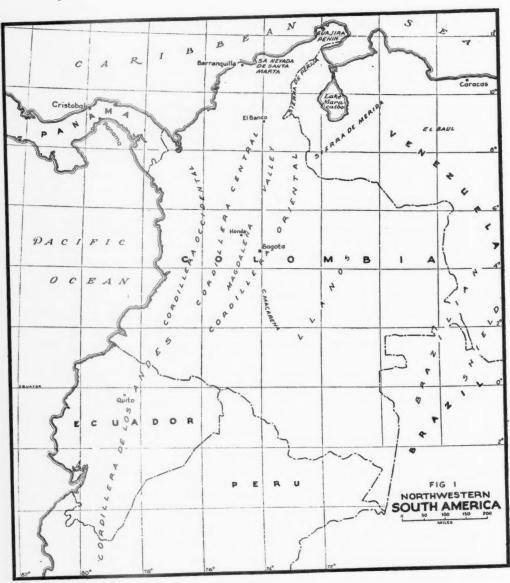


Fig. 1

Cordillera de los Andes commonly is referred to as three separate units, the eastern, central, and western Cordillera. Whereas the central and western branches of the Cordillera terminate in northern Colombia, the eastern branch extends northeastward into Venezuela, forming the Sierra de Merida and the Sierra de Perija, respectively. The Sierra Nevada de Santa Marta, located approximately due east of Barranquilla on Long. 74° W., commonly is considered a separate physiographic unit.

Within the region under discussion the Andean Cordillera attains its greatest altitude in northern Ecuador and southern Colombia with peaks lying between 15,000 and 20,000 feet above sea-level. The Sierra Nevada de Santa Marta of northern Colombia also exceeds 15,000 feet altitude. The southern part of the central Cordillera is relatively higher than any parts of the eastern and western branches.

EVIDENCE OF TECTONIC FRAMEWORK

The parts of the Cordillera above 6,500 feet altitude are shown on the sketch map (Fig. 2). This map suggests that the Andean Mountain ranges exhibit two major trends which are approximately parallel with the predominantly northeast-and northwest-trending coast line of the continent.

On Figure 2 are shown the areas now exposing pre-Paleozoic and igneous rocks superimposed on the areas above 6,500 feet altitude. By this means a graphic picture is obtained of areas now topographically high and of those frequently high during the long period since Paleozoic time as compared with areas relatively low during parts of the same interval. The graphic separation of these two areas must reflect the framework of the rigid masses which were the controlling factors in the structural history of the region. Although it would be preferable to exclude the younger igneous extrusives from the area of rigid rocks representing the older framework, not all can be separated due to our present limited knowledge. In those cases in which they can be recognized the younger igneous rocks appear to be closely related with the older rigid masses and exhibit the same trends so that they do not alter essentially the picture of the framework. This statement refers particularly to Ecuador and southern Colombia.

The areas which exhibit evidence of having been frequently above sea-level since Paleozoic times, and those which are now at relatively high elevations, are referred to as positive and the others as negative.

The coincidence of the present topographically high areas with areas exposing

It is obvious that areas now exposing basement rocks were relatively high during sufficiently long periods to prevent sedimentation or to let erosion remove any sediments which might have been deposited. Where basement is now exposed at relatively low altitudes these exposures suggest either roots of old uplifts or lack of appreciable vertical movement. On the other hand, where basement is exposed at high altitudes either rejuvenation of old uplifts or recent uplift of a formerly stable area is indicated. In contrast to areas exposing basement at high altitudes are the areas exposing sedimentary rocks at similarly high altitudes. The fact that a great thickness of sediments was deposited and has not yet been removed by erosion suggests an area which was low with respect to its surrounding territory and was only relatively recently lifted to its present altitude.

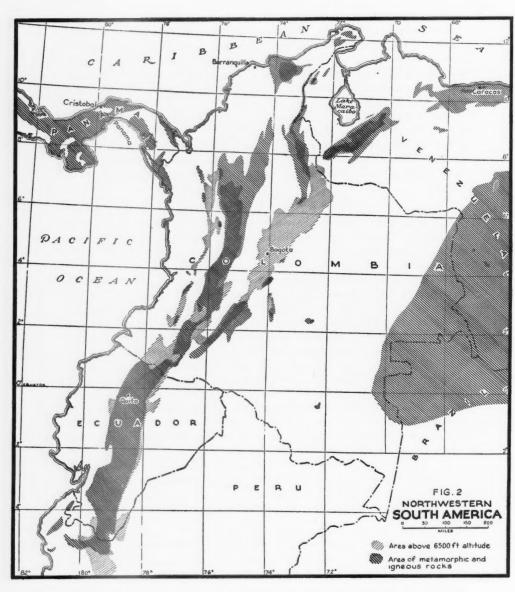


FIG. 2

pre-Paleozoic rocks (Fig. 2) suggests the following old positive masses: the Cordillera in Ecuador, the Cordillera Central and the Sierra Nevada de Santa Marta in Colombia, and the Cordillera Merida in Venezuela. In other words, these areas have been frequently above sea-level and perhaps mountainous since the beginning of the Paleozoic. Some of the other areas which are at present topographically high are at least partly reflected as old positive masses. The Cordillera Oriental between Lat. 3° and 7° N., however, appears to be a definitely much younger positive area. The sedimentary record of the area indicates that it was below sea-level in Cretaceous time and continued to be relatively low in early Tertiary time. The great uplift of the Cordillera Oriental, between Lat. 3° and 7° N., which began in early Tertiary time, was due to faulting of a great massive block accompanied by folding along major northeast-trending thrust faults.

The great Brazilian Shield, the somewhat mountainous area in the vicinity of Caracas, the Guajira Peninsula of Colombia, and the greater part of Panama are positive areas (Fig. 2) now lying below 6,500 feet. Panama appears to have been a relatively stable area with only slight oscillations during that part of geologic history for which the evidence is now discernible.

INTERPRETATION OF EVIDENCE

The sketch map (Fig. 3) indicates three types of trends: older positive trends which may or may not have been rejuvenated; younger positive trends exclusive of rejuvenated older trends; and negative trends.

The positive trends shown in Figure 3 are believed to represent the longest median lines of some of the major positive blocks as suggested by the evidence presented in Figure 2. The writer has attempted to eliminate from the map the confusing effect of minor elements resulting from the combination of several trends and has shown only those which are clear and persistent for a longer distance.

For the sake of brevity the writer will refer to northeast-southwest trends simply as "northeast" and to northwest-southeast trends simply as "northwest."

It appears that all major trends in northwestern South America, as expressed in the framework of old positive masses, areas of recent uplift, and also in the intervening negative areas, are predominantly N. 40° E. and N. 30° W.

A major northwest trend is apparent in the northern Cordillera Central of Colombia. It seems to continue southeastward into the Llanos where it is expressed in the Cordillera Macarena both topographically and as an ancient positive mass. Parallel with it and probably related to it is the Cordillera Occidental in its northern part. This uplift finds its expression as far north as Panama. A third northwest trending block is the old positive area of the Cordillera Occidental between Lat. 6° and 10° N. The same northwest trend is evident on the southwest slope of the Sierra Nevada de Santa Marta. The northwest trend again

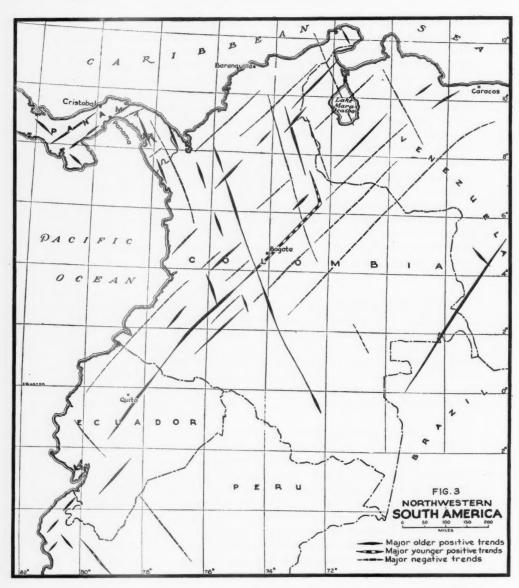


Fig. 3

appears in the old positive but recently stable areas of Panama, the Guajira Peninsula of Colombia, and El Baul of Venezuela. It is much less clear in the older rocks of southern Ecuador and northern Peru or in the western part of the Brazilian Shield.

Crossing the northwest trend at an angle of about 70° is a northeast trend which is expressed primarily in the present mountains although these mountains do not everywhere coincide with older positive masses. Where an old positive block exhibits the northeast trend it is ordinarily of very great elevation. In the Cordillera Oriental and the Cordillera Occidental between Lat. 3° and 6° N., the more recent northeast positive element is superimposed upon a formerly negative area. The northeast trend is definitely indicated to be younger than the northwest trend because the uplift on this trend has affected former negative areas as well as positive areas in which it is dominantly expressed. This applies to the area of Colombia, Ecuador, and western Venezuela only. The Brazilian Shield exhibits the northeast trend without prominent recent uplift.

The same trends are indicated in the negative areas intervening between the positive blocks. One of the most persistent of the negative trends is the northwest element of the Magdalena Valley. South of Latitude 5° North, the northeast trend is the dominant element although the northwest element is also apparent.

These trends shown in the negative areas (Fig. 3) are thought to represent essentially the longest median lines of major individual blocks. Additional median lines of minor individual blocks reflecting the same trends may be drawn on more detailed evidence in the Middle Magdalena Valley, and the other negative areas.

In the negative area of the Lake Maracaibo Basin, the northeast trend is shown in Figure 3 at equal distances from the margins of a generally negative area. The outline of the old positive area of the Cordillera Oriental, however, suggests the possibility of two northeast-trending negative blocks separated by a slightly uplifted parallel block crossing Lake Maracaibo.

In summarizing the foregoing interpretation it appears that the lines separating individual blocks whether they are old positive, young positive or negative blocks, do not run haphazard but form definite trends. In instances where the block has the shape of a simple elongate parallelogram this regularity is striking and the lines drawn in Figure 3 represent the medians of such parallelograms.

ADDITIONAL EVIDENCE SUPPORTING INTERPRETATION

If the hypothesis of continuous and intersecting trends is correct then two positive trends should result in the greatest uplift at the point of intersection. Intersecting negative trends, on the other hand, should result in the deepest basins. Intersecting positive and negative trends should compensate each other. Figure 4 indicates the principle graphically.⁵

⁵ Intersection of trends does not require a continuity of trends past the point of intersection. The statement regarding relative uplift at intersections of course applies to only a limited area

The intersection of the most prominent and continuous northeast and northwest trend in the region under discussion actually coincides with topographic features of greatest elevation. This is particularly evident in central Colombia.

In the same general area the positive northwest trend of the Andes intersects with the negative northeast trend of the upper Magdalena Valley near Honda. These two movements should compensate each other. Basement rock at shallow depth in the vicinity of Honda is in agreement with this hypothesis. Similarly,

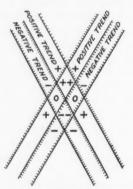


Fig. 4.—Intersecting positive and negative trends and resulting relative elevation.

where the positive northeast trend of the Cordillera is cut by the negative northwest trend of the lower Magdalena near El Banco, the two movements equalize each other. This is indicated by shallow basement near El Banco.

Finally, the greatest amount of downward movement in a given basin, and consequently deposition, should occur at the intersection of two negative trends. Actually, the greatest thickness of Tertiary sediments in the Middle Magdalena Valley occurs at the intersection of two negative trends at Lat. 7° N.

SEDIMENTATION AND STRUCTURE IN NEGATIVE AREAS

Logically, it should be assumed that areas of maximum deposition occur at the intersection of two negative trends. The fact that oil fields are located at

because of possible unequal amount of uplift on any particular trend. The relative downward movement of a negative area may be much greater than the relative upward movement of an adjacent positive area. Consequently, the area of intersection between a negative and positive trend might be slightly negative instead of being absolutely compensated. It should also be understood that where old positive trends intersect the present altitude, as a result of subsequent erosion, is not necessarily high. Relatively young volcanic rocks will further affect the present altitude and complicate the picture. It is therefore extremely significant that evidence supporting the theory on the basis of this principle can be recognized. The Sierra Nevada de Cocuy, marking the intersection of two trends of relatively young uplifts at approximately Lat. 6°30′ N. Long. 72°20′ W., is the best example of surface evidence conforming with the principle.

Lat. 7° in the Middle Magdalena Valley is not a coincidence but is conditioned by the maximum deposition as a result of maximum sinking where the two negative trends intersect. The location of the oil fields is also conditioned by folding forces applied from two directions, a prerequisite for closed structure. All the oil-producing structures in Colombia exhibit evidence of two trends which are the result of the framework we have been able to differentiate.

Although most structures of the pliable sediments in the negative areas reflect the two trends, the axes of the folds need not everywhere be parallel with the trends of the framework. If rotational forces are active, the axes of the folds are at an angle to the two directions of the frame. Northeast and northwest elements are apparent in the axes of all oil-producing anticlines in Colombia.

Evidence presented in the foregoing analysis further indicates that the forces producing the northwest-trending uplifts in the area under discussion were dominant prior to the more recent stress resulting in the northeast trend, as demonstrated by the later uplift of the northeast-trending Cordillera Occidental. Consequently, dominant northwest-trending folds probably were present on which the northeast-trending folds were superimposed. Field observations made by the writer in Colombia confirm that the northwest element reflected in the folded Tertiary sediments is older than the northeast trends which are now the apparent dominant structural feature. It appears that the forces causing northwest-trending folds decreased to the same extent as the forces causing northeast-trending folds increased. These observations are in agreement with the interpretation of the framework and the relative movements indicated in Figure 2.

ORIGIN OF FRAMEWORK

It is shown in the foregoing discussion that the pattern of the tectonic framework of northwestern South America exhibits two trends, a northeast and a northwest trend. The trends appear to reflect the orientation of large blocks, possibly controlled by the law of isostasy and separated from each other by zones of weakness.

If it is assumed that the zones of weakness are the result of compression, these zones could be due to either rotational or non-rotational compression. Under non-rotational pressure rigid material breaks at angles of less than 45° to the principal axis of stress. Rotational forces, on the other hand, result in fractures from 0 to 90° to the applied stress. Consequently, if non-rotational compression has been responsible for the zones of weakness separating the positive and negative areas in northwestern South America, the trends would indicate that the principal axis of stress was oriented approximately due north and south. In this case the angle to the principal axis of stress would be approximately 35°. However, rotational stress could result in the same pattern. The type and direction of the applied stress therefore can not be established definitely from the evidence on hand.

OTHER AREAS

Northeast and northwest trends similar to those in northwestern South America can be observed in the tectonic framework of both the eastern and western hemisphere. A northwest trend is prominently expressed in the Andes of Peru and northern Bolivia, in the southern tip of South America, the mountain ranges of Central America and the West Indies, in California, and the Rocky Mountains of Canada. The northeast trend is the dominant element in the Atlantic coast line of southern Brazil, the Appalachian Mountains, and the Aleutian Islands. Similarly, in the eastern hemisphere the two trends are expressed in Australia, New Zealand, New Guinea, Sumatra, the Philippines, India, Iran, the Arabian and the Red seas, and in some of the older mountain systems of Central Europe.

A map of pre-Cambrian structure prepared by R. Ruedemann (1922) shows prominent northeast and northwest trends practically throughout the northern hemisphere. North and south trends are indicated in the pre-Cambrian of Africa and western Australia. It will be noted that these north and south trends are reported to occur on the two oldest continents outside of the great oil-producing area. Ruedemann recognized that pre-Cambrian structure exhibits uniform directions over enormous tracts of the earth. The problem of pre-Cambrian structure deserves further study.

Available evidence suggests that northeast and northwest trends are the most dominant elements in the framework of the earth as far so we can recognize them today. These two major elements have had a far-reaching effect on the structure and stratigraphy of all post-Cambrian structure and stratigraphy, and ultimately on the accumulation of oil.

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⁶ Only the most important references from a local or regional point of view are shown in the list of publications. Where an author lists a complete bibliography on a specific area, as for instance, J. L. Anderson, 1945, reference to his publication is considered sufficient.

SAN PEDRO OIL FIELD, PROVINCE OF SALTA, NORTHERN ARGENTINA¹

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ABSTRACT

The San Pedro oil field, in the Province of Salta, is the most important of the seven fields of northern Argentina and has produced about half of the total of 24,800,000 barrels obtained to the end of 1944 from that region. These fields account for about 10 per cent of the crude oil production of the entire Republic. San Pedro itself produced 12,941,259 barrels of oil, or 27,771 barrels per acre recovery to the end of 1944. This is a relatively high recovery for Paleozoic oil.

The San Pedro field, like the others of the region, is situated in the Tarija Basin of Permo-Carboniferous age, with total sedimentary deposits probably exceeding 10,000 meters in thickness. The oil within the fields of this basin is considered to be primarily of Devonian origin and is found irregularly accumulated in various formations up to and including Pleistceene. In this field, the oil zones are just above the Devonian in the glacial sediments of the Permo-Carboniferous.

The structures of the Tarija Basin were formed during the Andean movement of Pleistocene age, there being no noticeable differential folding in the thick section from Devonian to Pleistocene. They are in a belt of about 100 kilometers wide between the "altiplano" and the "Chaco" plain on the east, and stand out as five or more long, parallel mountain ranges several hundred kilometers long. The characteristic form of the structures is a thrust-faulted anticline, and in a number of places it appears that the faulting has been the dominant feature, folding being somewhat superficial and late in the structural development.

The oil fields within the Tarija Basin are unique among those of the world in their relatively great age disparity between the deposition of the source beds (Devonian) and the first folding (late Tertiary) which could have afforded accumulation. From this it is inferred that possibly the generation and migration of oil from a source bed could be postponed, without adverse results, until the advent of the first effective folding.

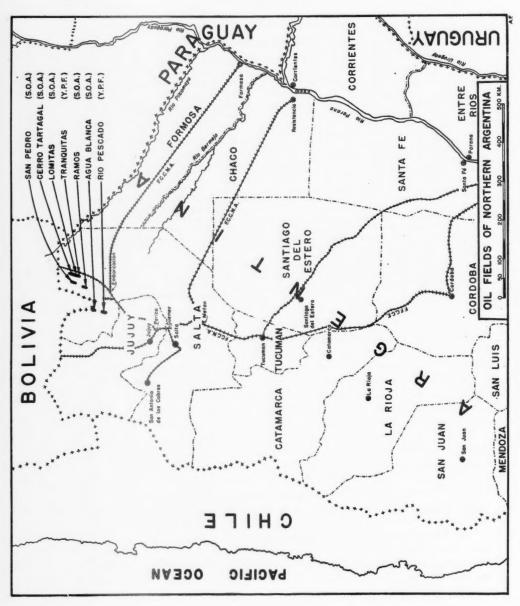
INTRODUCTION

The San Pedro field is one of seven oil fields which have been developed in the Province of Salta, northern Argentina (Fig. 1), as the result of serious exploration work begun in 1920. Prior to that time a small amount of shallow drilling had been done on a minor scale in the Province, and a little noncommercial oil produced from the vicinity of an oil seepage on what is now the small 500-meter wide concession (Mina República Argentina) of the Y. P. F. (Yacimientos Petroliferos Fiscales) cutting across the Lomitas field.

In 1920 the Standard Oil Company, S. A. Argentina, began extensive geological studies which resulted in the first commercial oil in northern Argentina being found in 1926 at Agua Blanca, followed by discoveries at Lomitas and Cerro Tartagal in 1927, and at Ramos and San Pedro in 1928. In 1927 the Y. P. F. acquired the small Mina República Argentina within the Lomitas field; in 1930 it opened the Tranquitas field—the south extension of Lomitas, and in 1933 discovered the Rio Pescado field.

The fields are all confined to the Tarija sedimentary basin, the south limit of which is at about the 23° parallel. Within the Argentine part of the basin 23 exploratory wells have been drilled in the search for additional fields, but without success.

- ¹ Manuscript received December 11, 1945.
- ² Geologist, Standard Oil Company of Argentina.



Frc. 1.-Index map. Location of oil fields in northern Argentina.

In 1940 the Province of Salta, like most of the other provinces in the Republic having prospects of oil, was declared a Government reserve, thereby restricting future exploration and development of new lands to Y. P. F.

The seven oil fields produced approximately 24,800,000 barrels of oil (about half having come from the San Pedro field) to the end of 1944, at which time the daily production was about 4,000 barrels, compared with 5,200 barrels at the end of 1943. Except for a few possible minor extensions, the felds are completely drilled in the known sands, and all have passed their production peaks. The future production is estimated at about 7,000,000 barrels. These fields give about 6 per cent of Argentina's total output.

LOCATION AND TOPOGRAPHY

The oil fields of northern Argentina (Fig. 1) are situated close to the Bolivian border in the Andean foothills, with the "altiplano" on the west and the plain of the "Gran Chaco" on the east. The foothills are in reality long parallel ranges separated by wide valleys and coinciding remarkably well with the structural pattern.

The San Pedro field is on the San Antonio Range, the second west from the Chaco plain, and has a topographic relief beginning from 500 meters on the flanks and rising to 1,200 meters on the narrow crest, the over-all configuration representing clearly a partly eroded, tightly folded anticline.

HISTORY

The San Pedro structure was studied by several Standard Oil Company geologists, the first record being that of B. H. Frasch who, in 1921, included the area in a regional reconnaissance. In 1926 and 1927 San Pedro and adjoining areas were mapped in semi-detail by R. W. Richards, and in 1931 the writer made a detailed study of San Pedro structure.

Shortly after the investigation by Richards, 54 kilometers of road were built by the Standard and the discovery well was begun in December, 1927, and completed in July, 1928, producing 378 barrels per day, at the depth of 832 meters. Development was continuous to 1938, 53 wells having been drilled. Drilling was again commenced in 1942, and to the end of 1944 two additional completions were made in the northern extension of the field, making a total of 55 wells (Fig. 5).

STRATIGRAPHY

The sedimentary basin within which the oil fields are situated, called Tarija Basin, has its south limit near the 23rd parallel, or about 50 kilometers south of the San Pedro field, and extends northward into Bolivia for at least 500 kilometers

The sediments of this basin are very thick, probably exceeding 10,000 meters, and the rocks exposed in the structures range in age from Devonian to Pleistocene (Fig. 2), made up of three main groups: (1) dark gray Devonian shales; thickness 2,000+ meters; (2) sandstones, shales, "clay grits" or tillites, mainly of glacial

Stratigraphic Section - SAN PEDRO

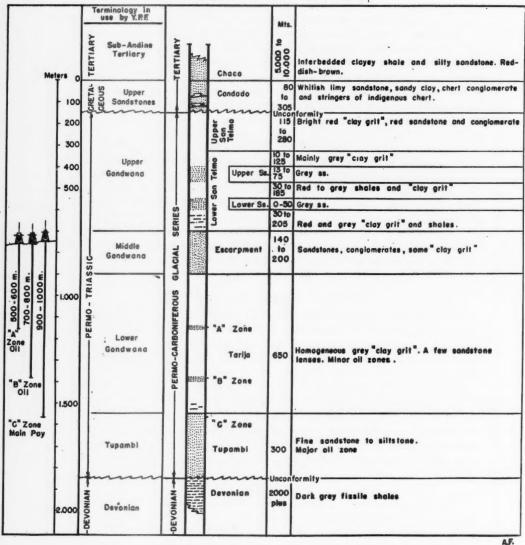


Fig. 2.—San Pedro. Stratigraphic section of formations represented in field.

origin assigned to Permo-Carboniferous; thickness 1,000-2,500 meters; and (3) reddish brown silty sands of continental deposition during Pliocene and Pleistocene; thickness 5,000 to 10,000 meters.

During the hiatus following the Devonian there was structural movement which formed a barrier and predetermined the south limit for subsequent deposition of the glacials in this direction. Within the basin, however, there is apparently good structural conformity between Devonian and overlying beds.

The Permo-Carboniferous sediments suffered a certain amount of erosion, although no folding, and the Tertiary sediments as we now see them, lie approximately parallel with them.

STRUCTURE

The structures of the Tarija Basin were formed during the Andean uplift of late Tertiary time, and the great thickness of the sediments as well as the relative plasticity of the Devonian shales favored the formation of a 100 kilometer wide belt of five or more long, thrust-faulted anticlinal ranges, remarkably parallel, and extending from the 23rd parallel northward 500 kilometers or more into Bolivia.

The ranges within which all of the fields of northern Argentina are situated represent structural uplifts in the magnitude of about 5,000 meters, and it is thought that faulting played the dominant role in this movement. Along the ranges are local "highs" separated by gentle saddles or otherwise influenced by faulting such as between San Pedro and Ramos. In one field (San Pedro) it appears that structural closure is necessary for accumulation of oil, while in others the oil is present several thousand meters vertically down-plunge, in lenses along the axis.

The anticline of San Pedro is relatively superficial as far as the big uplift is concerned and was formed, it is thought, in the overriding block of a large low-angle thrust from the west, the folding having developed from drag or resistance offered during its eastward progress. Apparently the shallower fault in the core of the anticline, shown in the cross sections through the field (Fig. 3), developed relatively late in the formation of the structure.

The maximum degree of folding is in that part of the structure occupied by the field itself. Within the 12 kilometers, south of the producing area of San Pedro there is a structural drop of about 1,000 meters, accomplished by a dying-out or unflexing of the fold, which at the southern end assumes a monoclinal west dip, associated with faults representing the last vestige of the anticline. Likewise, at the north the anticline flattens into a saddle preliminary to rising into the Macueta structure. In this northern part, beginning near the end of present production, there is a suggestion of another thrust fault of small displacement at the surface, trending along the east side of the crest.

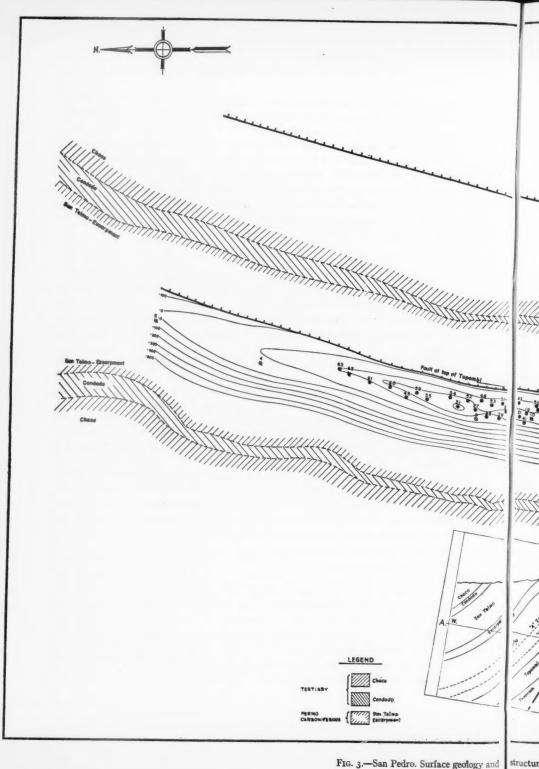
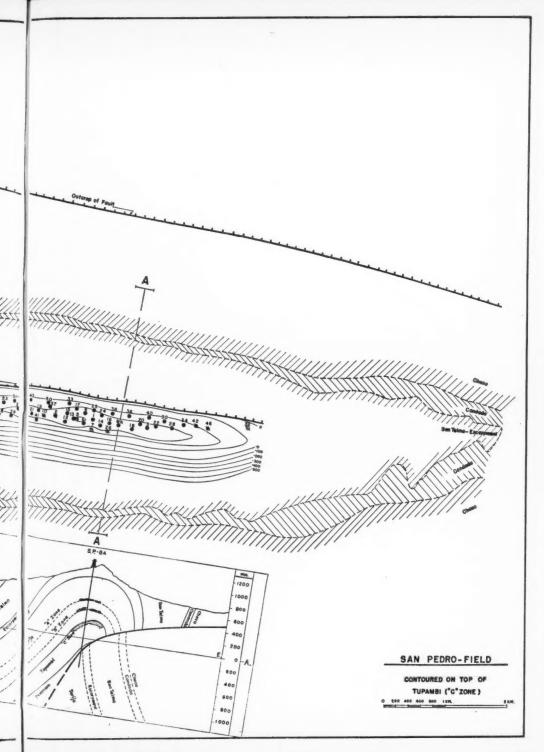


Fig. 3.—San Pedro. Surface geology and



structure at top of main sand, "C" zone.

and

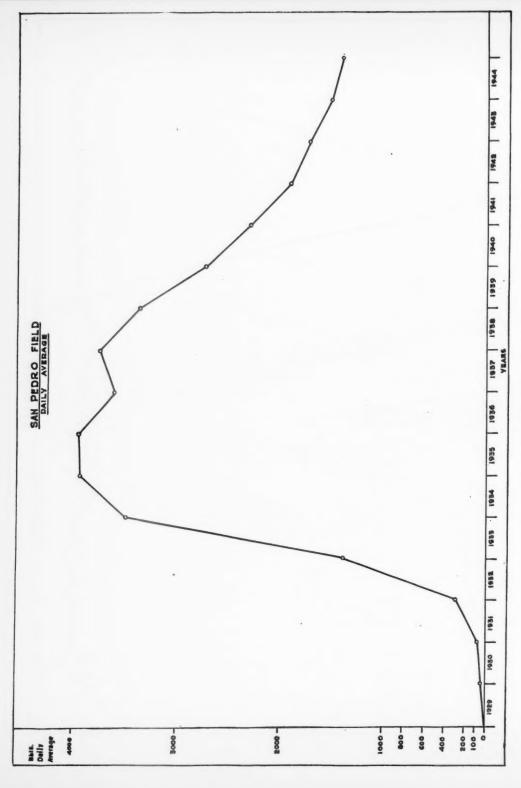


Fig. 4.—San Pedro. Production curve of field.

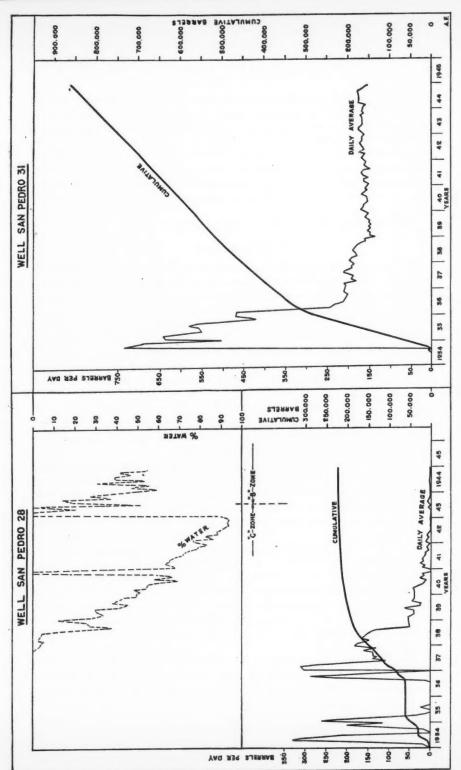


Fig. 5.—San Pedro. Production curves of two wells. Well SP-28 is representative of majority of wells, and well SP-31 is typical of 8 exceptionally good wells which furnish 67 per cent present production.

In the subsurface structure of the field, wells have shown that the west flank is steep, as illustrated on the cross section (Fig. 3) and that the crest is fairly gentle. Although the map and cross sections are constructed to show the presence of an east flank at the top of the Tupambi the main producing zone, it is quite possible that the dip remains about flat, there being no east flank present, and that the entire Tupambi is involved in a series of imbrication faults within a thick zone rather than just one break as represented on the cross sections. Such a condition as this may help to explain some anomalies of production and reservoir pressure.

The productive area is confined to a closure of 100 meters.

DRILLING DATA

All the wells were drilled with cable tools, rotary being used on two deepening jobs only. Depths range from 550 meters for the shallow sands, to 1,000 meters for the main "pay." The over-all drilling time varies considerably from well to well, although most of the completions were made within 4 to 8 months, depending on the amount of trouble experienced, such as fishing, straightening hole, under-reaming and testing. The casing program generally includes 4 to 5 strings, grading from 15-inch surface casing to $6\frac{5}{8}$ -inch cemented at the top of the producing zone. Casing depths are governed mainly by positions of water sands and caving hole. Once the well is completed, the surplus casings may be pulled.

OIL ZONES

Three oil zones are present (Figs. 2 and 3). The upper two, "A" and "B" zones, are in the Tarija formation and relatively unimportant. The third, or major one, is the "C" zone of uppermost Tupambi.

Outside of a few sand lenses, the Tarija formation of about 650 meters thickness is lithologically homogeneous dark gray tillite or "clay grit," very tough and massive. In composition the tillite is made up of 10 to 25 per cent coarse sand grains and here and there a striated pebble, distributed without assortment in a matrix of hard clay. The sand lenses are formed, presumably, by subaqueous assortment.

The "A" zone is in about the middle of the Tarija, at a drilling depth of 500 to 600 meters and is irregular in stratigraphic position, thickness, areal extent and productivity. In the one electric log (Fig. 6) taken in the field, the over-all thickness is indicated to be about 35 meters, but it is felt that this is excessive in comparison with the other wells and that the ordinary interval would not exceed 5 meters. The oil is closely associated with water sands, and production is confined to the central part of the field, the restriction possibly being due to lensing.

The "B" zone, also confined to the central part of the field, is even more spotted in lateral and vertical extent than the "A" zone, and less important commercially. The "B" zone sand is noted in the electric log of well 8A as being

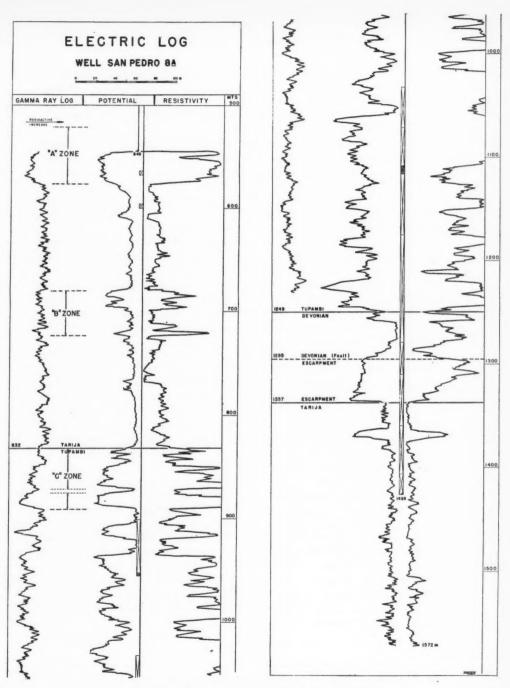


Fig. 6.—Electric and gamma ray logs of well SP-8A. Apart from fragmentary intervals, this is only electric log taken in field.

fairly well developed, but only the "A" zone gave production during the plugging-back and testing program subsequent to deepening. However, at the northern end of the field the last well to be drilled, SP-62, had a fair showing of oil in the lower part of the Tarija in somewhat the position of the "B" zone, perhaps indicating another small area of accumulation.

About 15 wells obtained some oil from the "A" or "B" zone, mainly the former while drilling down to the main sand. Production ranged from a few barrels per day to about a hundred barrels initial, although in all cases it dropped off rapidly. A total of 255,000 barrels has been produced, and the future expectation from the 7 wells (5 in "A" zone and 2 in "B" zone) now producing is proportionately small. The average daily output per well from the "A" and "B" zones is 12 bar-

rels, the greater part of which is produced by one well (SP-8A).

The Tupambi formation is about 300 meters thick, although some of this may be repeated by faulting. The electric log (Fig. 6) indicates sandstones with thin clay partings, but in reality the formation is made up of hard siltstone and only a minor amount of porous, fine-grained sandstone has been noted. Of eight cores, the average porosity was 12 per cent. Also, there are many slippage planes throughout, and these invariably show oil. However, in the producing interval there is some coarse, soft sand which has been noted from cuttings, but the thickness is not known.

The wells have an average maximum penetration of about 60 meters in the Tupambi, which interval includes both the upper and lower "C" zone. Judged from the electric log, the first 40 meters correspond with the upper "C" zone, embracing 4 or 5 sandstone bodies, and the following 20 meters are the lower "C" zone which has only one sandstone body. The over-all electric log sandstone is about 20 meters for the upper zone and about 9 meters for the lower. There are insufficient cores from which to evaluate the amount of porous sand, but the cores do show enough impermeable siltstone to say that less than half of the over-all 29 meters can be classed as effective sand.

Since the sands of the "C" zone are seen only from the electric log of SP-8A (and partially from offsetting well SP-16), and only one well (SP-16) has more than 2 or 3 cores in the producing interval, it is not possible to determine the spread of the individual bodies or what changes take place from sedimentary or structural causes. In general, the sands are thought to have had a widespread deposition, but to have been influenced to a great extent by faulting, and in the northern part of the field to be affected by lateral gradation such as change from sandstone to the "clay grit" as in the overlying formation. In the matter of correlation, it is of interest to note that while the electric and gamma-ray logs of SP-8A correspond perfectly, no satisfactory correlation of the Tupambi has yet resulted from the gamma ray alone.

WATER TABLE

It was thought that the original oil-water contact was at about plus 150 meters, which is about 150 meters below the top of the "C" zone at the highest

part of the structure. However, a uniform water table is somewhat questionable, and in view of erratic production and non-uniform flooding of wells it seems as though the water also may be influenced by faulting. A further suggestion is that it may be in thin sands even within the oil series.

A total of five wells, some along the west flank, and a few of those higher on the structure have already gone to water. Of the present 26 active wells, 13 are making an average of 18 per cent water.

PRESSURE MAINTENANCE

From 1933 to 1943 inclusive, 3,975,534 M.C.F. or 32 per cent of the produced gas was returned to the "C" zone sands through 5 crestal wells. However, recently there has been insufficient surplus gas to continue the practice. Although supporting concrete evidence can not be cited, it is assumed that the return of gas was beneficial to the reservoir.

FORMATION PRESSURE

The original formation pressure, corrected to 900 feet above sea-level, was estimated to have been about 740 pounds. A marked drop in pressure was registered during the early stage of the field, and another began in 1940.

Viewed individually, the wells show considerable irregularity of formation pressure, probably due to structural causes, such as the faulting already mentioned. On the whole, that of the southern part of the field is low—less than 300 pounds, and that of the northern end high—more than 500 pounds, the line of separation having been abrupt all during the development of the field, and has suggested a structural or sedimentary barrier.

PRODUCTION DATA

The following statistics are as of the en	nd of 1944.
Number of producers drilled Number of dry holes drilled	49 6
Total number of wells drilled	55
Number of active wells, "A" and "B" zones Number of active wells, "C" zone	7
Total number of active wells	26
Number of wells shut in or suspended	17
Number of wells abandoned	12
Number of wells flowing: Number of wells on gas lift: Number of wells on pump: 1 "A," "B" plus 4 "A," "B" plus 2 "A," "B" plus	4 "C" 8
Total production "A" and "B" zones Total production "C" zone	254,975 bbls. 254,986,284 bbls.
	12,941,259 bbls.

Daily rate "A" and "B"
Daily rate "C"

Total daily rate
Average net G.O.R. per well during 1944:
Area under development:
Character of oil: "A" and "B" 35°, "C" 44° A.P.I. Paraffine base.
Very good for lubricating oil and high octane gasoline.

Early initial:
S00-1,000 bbls. per well
Yield per acre to end of 1944 is 27,711 bbls.

An exceptional feature of the field is that out of the 26 active wells, 67 per cent of the daily production is coming from wells which are outstanding in the amount of oil they have produced, and in their production curves which show no decline slope. (Well SP-31 of Fig. 5 is representative of this group.) These 8 wells, widely distributed along the crest or slightly on the east, also suggest a complex reservoir condition for the "C" zone, such as would be expected from faulting. Their production curves are characteristic of forceful water drive, and one well with the same characteristics was recently killed by water.

The other well shown in Figure 5, SP-28, is more representative of the normal well of the field.

To illustrate further the characteristics of the producing wells, they have been grouped as follows.

		Daily Rate		Rate	Cumulative			
			Per	Well		Per Well		
			Total	Avg.	Total	Aver.	Well No.	
Group I 8 wells	"C" zone	8 good wells on re- stricted production; 2 pumping and 6 flow- ing	814	102	3,464,642	433,080	25, 31, 36, 48, 50, 51, 52, 54	
Group II	"C" zone	ii wells on unrestrict- ed production	322	29	3,236,955	294,269	6, 14, 17, 30, 38, 39, 45, 59, 60, 61	
Group III 5 wells	"C" zone	5 wells having pro- duced from "C" and subsequently plugged back to "A or "B": zones	_	_	994,402	198,880	3, 12,19, 27,28	
Group IV 7 wells	"A" and "B" zones		82	11.7	158,475	22,639	3, 8A, 12, 19, 23, 27, 28	
Group V	"A," "B" and "C" zones	23 inactive wells, aban- doned or shut in	allerine		5,084,665	22,107		
Group VI I drilling	Tarija	well drilling at end of 1944. Oil from test of lower Tarija for- mation	t	_	2,120	-	62	

SOURCE AND ACCUMULATION OF OIL

The source bed for the oil of the region is considered to be the Devonian. Its minimum thickness of 2,000 meters of dark gray shale constitutes the only marine

deposit in the exposed section, and it is thought to be underlain by rocks somewhat metamorphosed. Numerous oil seepages issue from the shales where exposed in structures.

The oil is considered to have migrated from the Devonian into the upper formations, faults and fractures having facilitated the movement. During the deepening of SP-8A, traces of oil were found in cores throughout the Tupambi; and also in the sandstones of the repeated Escarpment immediately below the fault. Judging from the negative results of this well when tested, it is concluded that the showings were comparable with seepage oil passing through the rocks, and for that reason lacked the necessary saturation.

There are surface oil seepages on both west and east flanks.

As previously mentioned, the main reservoir of the San Pedro field is the uppermost part of the Tupambi; with minor accumulation present in the overlying Tarija. Among the fields of northern Argentina-Bolivia, oil is found at various horizons ranging from Devonian up to late Tertiary. The positions at which accumulation took place appear to have been influenced, among other factors, by the character of fracturing and faulting and also by the amount and type of cover over the structure.

It is interesting to note, in San Pedro as well as the other fields of northern Argentina-Bolivia, that there is an exceptionally long interval of time between the deposition of the assumed source bed of Devonian age and the advent of accumulation with the first structure-forming movement dated in late Tertiary (Pleistocene), after the deposition of possibly more than 10,000 meters of sediments. Furthermore, there does not appear to have been any line of weakness or "grain" in the Devonian to pre-determine the site of folding or to facilitate migration of oil into the overlying formations until the first structure-building movement of late Tertiary. However, due to the intense folding, accompanied by flowage, it would now be impossible to recognize any slight shortening of section attributed to progressive uplift during sedimentation, such as found in structures of many oil fields and which might have had an influence upon accumulation before formation of the structure proper.

Therefore, it may be stated that, in this region, the main consideration with reference to accumulation is the advent of the first folding, irrespective of the relative ages between it and the source bed. This feature is of particular interest when it is realized that other oil fields of the world which can be brought to mind have only a small disparity in age between the source bed and the first folding responsible for accumulation.

The question may be boiled down to the fact that in most oil provinces structural movements were frequent in comparison with the exceptionally long period of quiescence experienced before the formation of the fields in the Tarija Basin, and the inference may be made that the generation and migration of oil from a source bed could be postponed indefinitely without adverse results.

GEOLOGICAL NOTES

STRATIGRAPHY NEAR CABORCA, . NORTHWEST SONORA, MEXICO¹

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Like much of Mexico, the stratigraphy of Northwest Sonora is known only vaguely. Most of the little that is known resulted from reconnaissance investigations undertaken by American and European oil companies. W. T. Keller (1928) described a part of the area under consideration and C. L. Baker, whose results were reported by Schuchert (1935), examined most of this region. In 1942 interest in the Caborca area revived when the discovery of Cambrian trilobites was announced by A. Stoyanow. The specimens were found by Isaurao G. Gómez L. and L. Torres during an investigation of the region for Petróleos Mejicanos and were submitted to Stoyanow for identification. The announcement of undoubted Cambrian in Mexico later led to arrangements for a joint investigation of the Paleozoic strata of the Caborca area by a member of the Smithsonian Institution staff and a representative of the Instituto Geológico de Méjico.

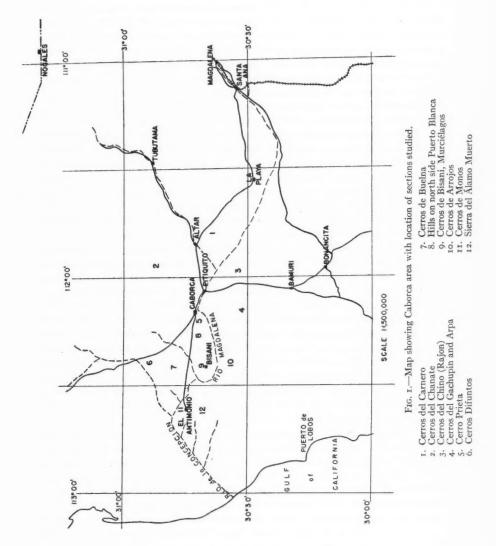
As the result of this union of forces, the writers visited Caborca, located in the Altar District, 112 kilometers (70 miles) south and 112 kilometers (70 miles) west of Nogales, Arizona. Five weeks were spent in the spring of 1943 and another 6 weeks in the late winter and early spring of 1944. The investigations included a brief survey near Altar and more detailed investigations east and west between Pitiquito and El Antimonio, a distance of about 64 kilometers (40 miles). The hills were also studied with some care, for 24 kilometers (15 miles) north and 24 kilometers (15 miles) south of Caborca. In this work, Arellano prepared the maps and studied the structure and physical geology. Cooper was chiefly responsible for collecting the fossils and stratigraphic data. Gratifying results established a long Paleozoic column including Lower and Middle Cambrian, possible Ordovician or Silurian, Upper Devonian, Lower and Middle Mississippian, and Middle Permian. In addition to the Paleozoic rocks, a long sequence of pre-Cambrian strata was measured. A long section of Mesozoic rocks (Triassic to Lower Cretaceous) also occurs but was not studied in detail.

This preliminary report is designed to correct some errors that have crept into the literature of the Caborca area, and it will serve until the extensive report, including description of the faunas by qualified authorities, is finally published.

¹ Published with the permission of the secretary of the Smithsonian Institution and the director of the Instituto Geológico de Méjico. Manuscript received, February 5, 1946.

² United States National Museum.

⁸ Instituto Geológico de Méjico.



In the neighborhood of Altar two mountain masses occur: one called Cerros del Carnero, southeast of the village, and another forming a long ridge, extending northwest, called Cerros del Chanate. The Cerros del Carnero extend for 15 kilometers (q miles), southwest of the main highway to Santa Ana. In the western end of these mountains the rocks were examined and determined to be finegrained schists and coarse-grained quartzitic to gneissic rocks with some interbedded limestone lenses overlying an intrusive mass of gneissic granite. The total thickness of these sediments is not known but it must be nearly 1,000 meters. The structure is roughly monoclinal, with dips varying from almost flat to 37° in a general easterly direction. According to Stoyanow (1942, p. 1264), these are the Altar schists which constitute the Altar headland of Archeozoic Mazatzal land, the oldest rocks in this part of Sonora. The writers are unable either to corroborate or to deny the age of these rocks. They are among the most strongly metamorphosed masses seen in the area but inasmuch as they are intruded by granite their degree of metamorphism may not be a criterion of age. These observations, complemented by what has been published on the Paleozoic of Sonora, give no support to the concept of such a "headland."

Examination of the northwest and southeast ends of Cerros del Chanate extablished the backbone of these hills to be an andesite flow of considerable thickness tilted fairly steeply toward the east. Above it occurs a thick sequence of yellow, greenish, and reddish shales with thin limestone lenses, reddish conglomerates, and red sandstones containing silicified wood and a few marine fossils. The latter were determined by J. B. Reeside and R. W. Imlay of the United States Geological Survey to be Lower Cretaceous (Albian-Aptian) in age. Southeast of Altar, beyond La Playa, the road to Santa Ana passes through hills composed of similar rocks which contain Lower Cretaceous fossils at a few localities. Conglomerates, possibly of the same age, also occur southeast of Pitiquito and on the east side of Difuntos Hills, 23 kilometers (14 miles) northwest of Caborca and on the northern end of Lista Blanca Hills, 10–12 kilometers (6–7 miles) west-southwest of Caborca.

Along the main road between Altar and Pitiquito bedrock was seen only near Pitiquito. The long Cerros del Chino (or Cerros del Rajon) extending south-southeast of Pitiquito and the small hills west of them, Cerros del Gachupin and Arpa, yielded fine sections of rocks dated by the writers as pre-Cambrian in age. In these hills a tripartite division of the rocks is possible. The lowest division, about 450 meters thick, consists of fine-grained sandy shales, thin-bedded lime-stone and fine-grained sandstone with some heavy layers of white quartzite at the top. The base is unknown because these strata rest on a coarse-grained, pink intrusive granite. Overlying the uppermost quartzite of the lower group occur 150–200 meters of dark gray dolomite abounding in Cryptozoa in the upper 65 meters. Above the cryptozoan bed occurs the third division of the pre-Cambrian, a section of more than 1,000 meters, consisting of thin-bedded, commonly brecciated, gray dolomite with thick channels of clean white quartzite.

The sections in the Cerros del Gachupin and Arpa include representatives of all three divisions of the pre-Cambrian, but Cerros del Chino are composed chiefly of the two upper groups. The latter section starts in the upper quartzite of the lowest group. The structure is a complicated, faulted monocline with a moderate dip toward the east, steepening to verticality on the northeast front. The gray dolomites with quartzite channels are well developed particularly at the north end of the range. At the northeast base of Cerros del Chino occurs a broad pediment of probable Lower Cretaceous conglomerates, redbeds, purple shales, and volcanics extending at least 2-3 kilometers (2 miles) east-northeast of the range.

Between Pitiquito and Carborca, hills of granite and other igneous rocks occur on the south side of the road. On the east edge of Caborca and extending 20 kilometers (12 miles) northwest along the east side of the road to Sonoita, occur many low hills of igneous and sedimentary rocks. The sediments are mostly dolomites with interbedded quartzites. One prominent hill, composed of these sediments, is located at the cyanide mill on the east edge of town. These rocks were difficult to date until large algae were discovered in dark intruded dolomites on a low hill north of the railroad embankment at the north end of C Street North between the abbatoir and the cemetery. The beds on this side of Caborca thus belong in the middle division or algal bed of the pre-Cambrian, and the dolomites with channel quartzites along the Sonoita road are assigned to the upper light gray dolomite division.

The Sonoita road leading northwest out of Caborca is the approximate boundary between pre-Cambrian and Cambrian rocks which occur at intervals for about 20 kilometers (12 miles) west of Caborca. The middle Cambrian Arrojos formation was described by Stoyanow (1942, p. 1263), but this section is neither the best nor most complete in the region. The finest Cambrian sequence is that on the north side of Puerto Blanco, north of the Proveedora mine about 10-12 kilometers (6-7 miles) due west of Caborca. The rocks are nearly vertical at this place and a section of 1,450 meters, beginning on the west side of the hills, was measured from Lower into Middle Cambrian. Thin-bedded sandy limestone, abounding in Obolella, and interbedded quartzite occur at the base. Above this are more than 200 meters of white quartzite and dark shale. Olenellus extends for nearly 600 meters from the bottom of the section, occurring both in the quartzite and in the limestone. There is doubt about the age of the dark limestone for some 100 meters above the highest Olenellus, but above this interval shales, limestones, and dolomites about 700 meters thick are definitely Middle Cambrian in age. The shaly lower 270 meters of the Middle Cambrian contain Glossopleura, Clavaspidella, and other Middle Cambrian trilobites.

The middle part of the Cambrian sequence, embracing the thick quartzite with Olenellus, an interval of thin-bedded limestone with Olenellus and the roometer massive limestone of uncertain age previously mentioned occurs in several hills in and near Caborca. The most accessible is Cerro Prieto about 2.5 kilometers $(r\frac{1}{2} \text{ miles})$ southwest of the village. This hill was previously identified as Middle

Pennsylvanian in age, Caborca series (Gamusa beds), on the basis of Chaetetes milliporaceous said to have been collected on its upper surface (Schuchert 1935, p. 138). Collections were carefully made at this place and Olenellus was found to be common in the lower thin-bedded layers and myriads of Cambrian Girvanella were found on the upper surface of the thick, massive, dark capping limestone. This capping ledge is the same limestone that occurs between the Lower and Middle Cambrian in the long section at Puerto Blanco. The same sequence is present in Cerros de Buelna, 15 kilometers (9 miles) northwest of Caborca. In Arrojos Hills, 20 kilometers (12 miles) west-southwest of Caborca, a short sequence of Lower Cambrian, beginning near the top of the quartzite, is present on the west face of the hills and a long sequence of Middle Cambrian overlies it and includes the shales that produced the first trilobites found in Mexico, Glossopleura and Alokistocare. In Cerros Difuntos, 22 kilometers (14 miles) northnorthwest of Caborca, Lower Cambrian appears in the east hill and the Middle Cambrian is exposed in the larger western hill.

A group of small hills occurs in and near the settlement of Bisani about 22 kilometers (14 miles) west of Caborca. Four small hills on the west edge of the settlement are composed of dolomite with interbedded quartzite. The only fossils found are poorly preserved crinoid stem segments which do not afford a sound basis for age determination. Lithologically, the beds suggest Ordovician or Silurian dolomites.

Northwest of Bisani about 3 kilometers (2 miles) occur Cerros Murciélagos, three small hills composed of limestone and dolomite. The east end of the largest hill and the small elongate hill just south of it yielded poor specimens of brachiopods, corals, gastropods, and stromatopores which date the enclosing sediments as low in the Upper Devonian. Two hundred eighty meters of Devonian sediments were measured.

Two kilometers (14 miles) west-northwest of Bisani and lying between the settlement and Cerros Murciélagos occurs another low hill composed of limestone abounding in silicified fossils including corals, brachiopods, and mollusks which date these sediments as fairly early Mississippian in age. One kilometer (1/2 mile) west occurs another low hill that yielded numerous specimens of the brachiopod "Rhipidomella dubia" which is believed to correlate these sediments with the Ste. Genevieve formation of the Mississippian and the lower part of the Paradise formation of Arizona.

Between Bisani and El Antimonio, a distance of about 24 kilometers (15 miles), no bedrock was seen. The Monos Hills lie about 2.5 kilometers (1½ miles) northeast of El Antimonio and the Sierra del Álamo Muerto extends for a considerable distance south. The Monos hills contain a sequence of more than 500 meters of Permian rocks (Monos formation) which were originally described by Keller (1928, p. 327) as Pennsylvanian in age. In the lower part of the section at the north end of the hills, numerous *Parafusulina* occur which were dated by C. O. Dunbar, Yale University, as Word in age. Near the top of the sequence A. K. Miller (1945) described a goniatite, *Waagenoceras dieneri* Böse, collected

by the writers, which dates this part of the section as Word also. Thus the entire sequence is of Word age and the other elements of the fauna have close affinities with the Phosphoria assemblage.

Unconformably overlying the Permian is a long sequence of Upper Triassic rocks which have been studied by Charles L. Baker, whose section was published by Burckhardt (1906, p. 6), and the fossils identified by Perrin Smith were listed by R. E. King (1939, p. 1657). During the course of work on the antimony mines Donald White discovered fossils in the foothills of the Sierra del Álamo Muerto, which were identified by J. B. Reeside, Ir., as Lower Jurassic in age, These fossils suggest that the main mass of the Sierra del Alamo Muerto is Jurassic or younger

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pp. 1255-82.

AGE OF PENTERS CHERT, BATESVILLE DISTRICT, ARKANSAS1

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Recent geologic mapping in the Batesville district, Independence and Izard counties, north-central Arkansas, has resulted in the discovery of fossils in a thin gray argillaceous limestone in the Penters chert. These fossils confirm the earlier suggested Camden (Lower or Middle Devonian) age of the Penters.3 Unfossiliferous at its type locality near Penters Bluff and at other described localities north of Pfeiffer, Arkansas, the Penters chert, because of its stratigraphic position and lithologic character, has been correlated not only with the Camden chert of Tennessee, but also the Clear Creek chert of southwestern Illinois and the lower member of the Arkansas novaculite of west-central Arkansas and southeastern Oklahoma.4 The Pinetop chert of southeastern Oklahoma5 and the Salli-

(1922), pp. 32-34.

¹ Published by permission of the director of the Geological Survey, United States Department of the Interior. Manuscript received, February 23, 1946.

² Geologist, Geological Survey.

³ H. D. Miser, "Manganese Ore in the Batesville District, Arkansas," U. S. Geol. Survey Bull. 715 g (1920), p. 98.

"Deposits of Manganese Ore in the Batesville District, Arkansas," ibid., Bull. 734

⁴ Ibid.

⁶ H. D. Miser, "Carboniferous Rocks of the Quachita Mountains," Bull. Amer. Assoc. Petrol. Geol., Vol. 18, No. 8 (1934), pp. 974-75.

saw sandstone of northeastern Oklahoma⁶ have been correlated with the Camden chert on the basis of their faunas. The Fortune formation of southwestern Missouri⁷ recently has been correlated with the Penters chert.

The limestone at the base of the Penters chert is fine-grained, light gray, argillaceous rock containing small pyrite cubes. It varies from 3 to 6 feet in thickness. The limestone bed underlies 10 to 40 feet of typical dense dark gray Penters chert and overlies St. Clair or Lafferty limestone of Niagaran (Silurian) age. In one manganese prospect on the northeast side of Sawmill Hollow (N. 1/2, NE. 1/4 Sec. 21, T. 14 N., R. 6 W.), where the Silurian limestone is not present, the gray argillaceous limestone bed of the Penters chert rests on 0.5-1.0 foot of clay residual from the Cason shale (Ordovican), which in turn rests on an uneven solutional surface developed on manganiferous Fernvale limestone (Ordovican). The gray limestone and overlying dark gray chert were believed by Miser to be part of the Boone chert (Mississippian).

The contact of the light gray pyritiferous limestone with the overlying darkgray chert is believed to be conformable as shown in field relations observed at manganese prospects in Sawmill Hollow. The limestone grades upward through 1.5 feet of interbedded argillaceous limestone and lenses of dark gray chert. The contact of the limestone with the overlying chert near the mouth of Rutherford Hollow (E. 1/2, SE. 1/4 Sec. 32, T. 14 N., R. 6 W.), however, is sharp, suggesting a local area of erosion prior to the deposition of the chert. Miser reports,

a small quantity of gray fine grained limestone at and near the base of the Penters chert in the vicinity of Penters Bluff and Walls Ferry on the western edge of the district,⁸

and it is possible that the two limestone intervals are correlative.

Fossil collections from the limestone in Sawmill Hollow and Rutherford Hollow were submitted to G. A. Cooper, of the United States National Museum, who reports,

These collections contain the brachiopod *Leptocoelia flabellites*. This is not the common *L. flabellites* of the Oriskany, but is the same as that usually assigned to this species and occurring in the Camden chert of Tennessee. These collections thus establish the Camden age of the limestone.

The following species are listed by Cooper from the collections: "Ambocoelia" n. sp., Leptocoelia flabellites (Conrad), Rhipidomella sp., Platyceras sp., Strophostylus sp., Phacops cristata Hall.

⁶ Charles Schuchert, "Devonian of Oklahoma with Special Reference to the Oriskany and Camden Formations," Bull. Geol. Soc. America, Vol. 33 (1922), p. 668.

⁷ J. G. Grohskopf, E. L. Clark, and S. Ellison, "The Fortune, a New Devonian Formation in Southwestern Missouri," *Missouri Geol. Survey and Water Resources*, Appendix IV, 62d Bien. Rept. (1943), pp. 1-17.

⁸ H. D. Miser, "Deposits of Manganese Ore in the Batesville District, Arkansas," U. S. Geol. Survey Bull. 734 (1922), p. 33.

CONODONTS FROM THE TRIASSIC OF SINAI (EGYPT)1

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Stratigraphic sections in Egypt and Sinai expose rocks of all geologic periods from the Carboniferous to Recent, with the exception of the Permian. The pre-Cretaceous sediments, however, are exposed only in a few large structures in the northern part of the country. The only known outcrop of Triassic is at Gebel Araif el Naga, northeast Sinai, near the Palestine border, where this formation was first noted a few years ago by geologists of the Geological Survey of Egypt.³

In connection with geologic mapping of Sinai in October, 1945, geologists of the Standard Oil Company of Egypt, during a detailed study of the area, measured the stratigraphic section and made fossil collections, in the course of which the writer sampled all exposed Triassic shales for micropaleontologic studies. Subsequent laboratory examination of these samples showed that some contain conodonts, a type of microfossil which has heretofore been found, with wide geographic distribution, only in rocks of Paleozoic age.

The conodonts which were found are typical of this group of microscopic tooth or claw-like fossils whose exact zoological affinity has long been a subject of controversy. The most common form in this as in most assemblages is that of a bar with several pointed denticles or cusps rising from one edge. The ordinary form of the bar is blade-like and slightly curved, with flattened denticles; rarely found is a straight, cylindrical bar bearing cone-shaped cusps. The whole fossil is almost invariably less than ½ millimeter long and is so fragile that unbroken specimens are seldom encountered. They are light brown to a clear, transparent amber color, with a shiny luster. Several different "genera" and "species" are represented, some of which are undoubtedly new. Lack of literature prevents identification and complete description of the fauna at the present time, but preliminary study shows the presence, among others, of types similar to "Euprioniodina" and possibly "Bryantodus." The ornamented leaf-shaped type of conodont found in many other older assemblages was not noted in the Araif el Naga fauna, but several specimens similar to "Gnathodus" approach the leaf-like type.

Conodonts, which were first discovered and described by C. H. Pander in 1856 from the Ordovician of the Baltic region, have been classified by most workers as parts of primitive fish. Many paleontologists, however, have preferred to consider the conodonts as jaws of worms, whereas other writers have

¹ Manuscript received, February 11, 1946.

² Standard Oil Company of Egypt. The writer wishes to thank the Standard Oil Company of Egypt and the Standard Oil Company of New Jersey for permission to publish this paper.

² Record of the occurrence was presented by Dr. Galal Hafez Awad in a paper read before the Institut d'Egypte on March 5, 1945. At the time of the present writing, Galal's paper had not yet appeared in print, but it should be published shortly in the Bulletin de l'Institut d'Egypte, Tome 28 (1945–46).

assigned them to the arthropods or mollusks. The strongest evidence put forth so far is in favor of relationship with, or very near to, the fishes, although the problem may never be solved to the satisfaction of all. In spite of the fact that no one knows the nature of the animal or animals of which conodonts are a part, these microfossils have been given "family," "generic," and "specific" names. Although widely adopted, this procedure is actually contrary to good practice in paleontological or biological nomenclature, because it creates a false taxonomy suggesting, among mere fragments, relationships for which there is no zoological evidence.

The work done so far on the Middle East conodonts throws no new light on the controversy regarding the zoological or taxonomic position of these microfossils, apart from any implications which may be drawn from the fact that their range is now known to extend into another major geologic era, the Mesozoic. Since the time of Pander, conodonts have been found to have a wide geographic distribution in Paleozoic rocks. They have been found from the Ordovician through the Permian, but were always thought to have become extinct at the end of the Paleozoic.

In order to establish the present find as an authentic occurrence of Triassic conodonts, it seems that three points must be proved: (1) that the microfossils in question are true conodonts; (2) that the sediments in which they are found are really Triassic; and (3) that they are indigenous to this formation, that is, not redeposited from some older formation.

Conodonts are ordinarily so distinctive as to be unmistakable; once seen, there is little chance that they will be confused with any other microfossils. Several geologists have examined the specimens found from Gebel Araif el Naga

and all agree that they are true conodonts.

The exact age of the Araif el Naga formation in which the writer has found conodonts is proved by the megafauna which it contains. The Geological Survey of Egypt calls it Middle Triassic on the basis of studies made in England. Fossil collections made by geologists of the Standard Oil Company of Egypt have been examined by the Geological Department of the Hebrew University, Jerusalem, under the direction of Leo Picard. They have designated the age of the fauna as "Middle Triassic (Muschelkalk)," with the assemblage bearing especial similarity to the Upper Muschelkalk and having slight affinity to the "Germanic" (Upper) Triassic of Europe.

The stratigraphic section at Araif el Naga exposes Triassic sandstone, limestone, and shale overlain by a thick section of Lower Cretaceous Nubian sandstone, which in turn is overlain by Upper Cretaceous and Eocene rocks. The generalized lithologic section of the pre-Cretaceous (listed from top to bottom) is, briefly, as shown in the following tabulation. The positions of the three conodontbearing shale beds are indicated; megafossils listed are as determined by the

Hebrew University paleontologists.

	Meters
Limestone, gray to reddish brown, hard, crystalline	18.4
Shale variegated sandy	1 0
Limestone, gray, white, and yellow Limestone, brown, crystalline, with poorly preserved fossils; thin interbeds of brown and	5.6
blue shale, two of which contain conodonts	10.7
Limestone, gray, thin-bedded, shaly	11.8
Shale, brown, gypsiferous	1.0
Shale, brown, gypsiferous	8.3
Limestone, hard, massive, lithographic. Limestone, gray, rubbly, containing some silty shale interbeds.	5.0
Limestone, gray, rubbly, containing some silty shale interbeds	9.8
Shale, greenish gray, containing conodonts. Limestone, gray to brown; fossiliferous, containing Pseudoplacunopsis fissistriata (Winkler)	1.0
other pelecypods, gastropods, crinoid stem ossicles, very rare echinoid spines Shale, gray to greenish gray with ½ meter limestone interbed; shale fossiliferous, containing Progonoceratites aff. P. primitivus Riedel or aff. P. atavus (Riedel); Adontophora aff. A. münsteri (Wissman); Myophoria laevigata Alberg; Ostrea montis caprilis Klipstein; Pseudoplacunopsis fissistriata (Winkler); Avicula sp.; other unidentified pelecypods	2.0
(Homomya? or Pleuromya?)	6.6
Ceratites, brachiopods, and pelecypods	4.7
Limestone, gray, hard, massive, lithographic. Limestone, brown, thin-bedded, with thin intercalations of shale; limestone fossiliferous, containing Germanonautilus bidorsatus (Schlotheim); compressed Nautilus and Ceratiles; Myophoria blakei Cox; Myophoria laevigata Alberg; Myophoriopsis cf. M. jordanensis Cox; Coenothyris vulgaris (Schlotheim); a variety of Terebratula julica Bittner; Schafhaüllia mellingii (Hauer); Spirostylus? sp.; Pseudoplacunopsis fissistriata (Winkler). In addition, a specimen of Paraceralies binodosus (Hauer), from an unknown hori-	
zon, probably comes from this bed	25.8
Sandstone, brown to white, cross-bedded	4.5
Limestone, brown, containing poorly preserved fossils	12.6
Shale, greenish gray to brown, with thin, brown sandstone layers	
Limestone, dark brown, hard, sandy, containing poorly preserved fossil casts	
stone; poorly preserved fossil casts and plant remains	47.5
Total	203.7

The 18 shale samples taken from the foregoing section were prepared for micropaleontologic study in the usual manner of crushing and washing, leaving a small washed residue from which the microfossils were picked. No Foraminifera were seen, but other microfossils noted in the shales include minute gastropods and pelecypods, fish teeth and scales, and rare, smooth-shelled ostracodes. Surficial examination of the unwashed shales with a binocular microscope showed only a very few, inconsequential conodont fragments, and nothing resembling a natural assemblage of these organisms.

Although Carboniferous rocks are known elsewhere in Egypt and Sinai, they do not crop out within 170 kilometers of Gebel Araif el Naga, nor are they found in Palestine and Transjordan, where older Paleozoics are exposed. Paleogeographic studies indicate, however, that the Carboniferous may be present in the subsurface at Araif el Naga.

In 1940 the writer found the first conodonts known from the Middle East in Carboniferous shales from well samples in and near the Ras Gharib oilfield, on the west coast of the Gulf of Suez. The age of the formation there is plainly proved by the associated megafauna, which includes spirifers, productids, and lepidodendrons. In addition, a few excellent scolecodonts were encountered in the Carboniferous, along with a small fauna of microscopic brachiopods, pelecy-

pods, gastropods, and rare ostracodes.

The Carboniferous conodonts are extremely small and fragmentary and probably unidentifiable. The Triassic assemblages, on the other hand, are much more diversified and abundant. This fact, plus their excellent preservation and their occurrence in at least three different shale beds which are part of a section not primarily made up of clastic rocks, seems to preclude the possibility of their being redeposited from Paleozoic sediments.

Discussion by E. B. Branson and M. G. Mehl, University of Missouri, Columbia,

March 15, 1946 .-

Mr. Eicher has recognized the importance of the conodont finds reported and has taken pains to establish the finds as indigenous to Triassic sediments. There could be but little if any doubt concerning the identity of the fossils and it appears that the age of the matrix is adequately established. In the light of some of our experiences, the possibility of an introduction of older conodonts into the accumulating sediments does not seem entirely eliminated. It is unfortunate that figures of the entire assemblage are not available so that it could be compared with well established faunas of earlier age. Although our knowledge of Paleozoic conodonts is still "spotty" it is well distributed across the geologic column and we can place a new fauna with fair accuracy.

Conodonts have been reported from the Hauptmuschelkalk of Neustadt, Germany, by Branson and Mehl, but they say: "However, granting that they came from the Muschelkalk, we do not consider that they are a record of Mesozoic condonts, but of residue

from Pennsylvanian or Permian formations."

In 1932, Frank H. Gunnell reported Mesozoic conodonts from Texas but Branson and Mehl do not consider the specimens closely related to conodonts. (*Pan-American Geologist*, Vol. 57, p. 317.)

ASPHALTIC SANDS FOUND TO OCCUR IN OIL FIELDS1

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Asphaltic sands, commonly known as "black sands," are commonly found to be non-productive of oil, although the appearance of sand specimens (cores) indicates that they are highly saturated with organic material. Some laboratory tests also indicate high saturation, but a study recently made by the United States Bureau of Mines demonstrates that the organic material in many of these "black sands" should be classified as "asphalt" rather than as "crude oil."

The importance of this conclusion is shown by the fact that retort saturation determinations indicate a reserve in these sands of many million barrels, which is largely non-recoverable if it is asphalt instead of crude oil, as usually believed.

Approved for publication by the Director of the Bureau of Mines. Manuscript received, March 8, 1946.

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In many oil fields in eastern Kansas, parts of the cores of the oil-bearing formation may appear to be exceptionally dark and highly saturated with oil. These "black-sand" sections vary widely in thickness throughout any field; in some places the black sand represents almost the entire formation thickness, and in other near-by wells it may be entirely missing. Saturation determinations made on "black-sand" cores by retorting commonly indicate the presence of 800 to 1,000 barrels of oil per acre-foot of sand, although determinations made by extraction methods ordinarily indicate much lower saturations.

These sands are found in many areas where water-flooding operations are in progress. When the cores are tested to determine the amount of oil that can be recovered from them by water flooding, ordinarily no appreciable amount of water can be forced into them at pressures up to 100 pounds per square inch and no oil can be recovered.

A representative core sample was selected. This was obtained from the Squirrel sand in the Paola Shoestring field in Miami County, Kansas. The well penetrated 41 feet of "sand." Laboratory flooding tests proved that no oil could be recovered from samples from the bottom 13 feet of the core, although retort saturation tests indicated the presence of 760 to 850 barrels of oil per acrefoot of sand. The porosity of this section was found to range from 17.9 to 19.7 per cent. (These values probably are low because of the difficulty of completely removing the "hydrocarbons" from the sand before testing it.)

Through the courtesy of the University of Kansas, a petrographic study was made. The University laboratory stated that the core was extracted with carbon bisulphide, benzol, ether, and chloroform, but at the end of the treatment it was nearly as dark as the original core. Mechanical analysis of the residue was not satisfactory because many of the particles were aggregates still cemented by "hydrocarbons." The major portion (38 per cent) passed a 120-mesh sieve and was retained on a 170-mesh sieve. Sixteen per cent passed a 250-mesh sieve. Three thin sections were prepared from the core, "all of which showed a very fine-grained, well-sorted, unstratified sandstone with bitumen completely saturating the rock." The report concluded, "There does not seem to be any evidence of a significant amount of clay or bentonite. Even if bentonite were present, it is doubtful whether water could act upon it in the presence of so much hydrocarbon."

Chemists of the Bureau of Mines studied the "hydrocarbons" in another specimen of black sand from the same core. Preliminary tests yielded the following results.

	Percentage
Water	. 0.6
Ash (mineral matter)	. 92.8
Total	
Material soluble in carbon bisulphide	3.0
Material soluble in benzene	2.3
Characteristics of material soluble in carbon bisulphide and in benzene. Dark, reddish	1

brown viscous "asphalt.

The material extracted by carbon bisulphide (3 per cent of the sample) was fractionated into the three components, "oils," "resins," and "asphaltenes." The method used is described in a forthcoming report. However, the fractions from the carbon bisulphide extract were found to contain traces of free sulphur, probably derived from solvent, so they were discarded and the material soluble in benzene (2.3 per cent of the sample) was fractionated into oils, resins, and asphaltenes, with the results shown as follows.

Fraction Oils, pentane-soluble Resins, pentane-soluble	Characteristics at 77° F. Light-yellow viscous oil Reddish brown, tacky, semi-solid which	Yield, Percentage 74.6
Asphaltenes, insoluble in pentane Extraction loss	melted on heating Black solid which decomposed on heating	17.2 5.4 2.8
		100.0

Similar, but less complete tests, also were made on 3 samples of "black sand" from the Quitman field, Wood County, Texas. These samples were from the Paluxy sand, which occurs in the area of the Quitman field at a depth of about 6,150 feet. The first two samples were from the same well, the third from a well on another lease. The results of the preliminary tests on these samples are as follows.

	Sample		
	I	2	3
	I	Percentage	
Water	0.2	O.I	0.4
Ash (mineral matter)	96.2	96.9	93.4
Ignition loss (organic matter)	3.6	3.0	6.2
Total	100.0	100.0	100.0
Material soluble in carbon bisulphide	0.7	0.3	3.2
Material soluble in benzene	0.5	-	2.2
Characteristics of benzene soluble material—Black, asphalt-like, semi-solid	3		
which melted or softened abruptly on heating			

The following results were obtained by fractionating the benzene soluble material from sample 3 into oils, resins, and asphaltenes.

Fraction Oils, pentane-soluble Resins, pentane-soluble	Characteristics at 77° F. Light yellow viscous oil Reddish brown, tacky, semi-solid which	Yield, Percentage 46.6
Asphaltenes, insoluble in pentane	melted on heating Black solid which intumesced and decom-	12.5
Extraction loss	posed on heating	38.2
Datiation loss		2.7
		100.0

The general similarity in the characteristics of the benzene soluble material from the Kansas and Texas cores is evident.

⁴ K. E. Stanfield, and Rethel L. Hubbard, "Asphalts from Some North American Crude Oils," U. S. Bur. Mines Tech. Paper (In preparation).

DISCUSSION OF RESULTS

It will be noted that the benzene-soluble material in the core sample from Miami County, Kansas, constituted only about 35 per cent of the total organic content of the sample. This was based on the assumption that the ignition loss represented only organic material and was not due partly to decomposition of inorganic material. The remaining 65 per cent of the organic matter was insoluble in benzene and may thus be classified as "asphaltic pyrobitumen." No attempt was made to isolate this material from the sand as asphaltic pyrobitumens generally are insoluble, friable solids that are virtually infusible and decompose upon being heated. As the "oil" found in the sample was viscous and amounted to only 26 per cent of the total organic matter in the core (all other fractions being solids or semi-solids), it is evident that little if any crude oil is present that could be produced by water flooding or other usual oil-field methods.

The benzene-soluble component was 35 per cent of the total organic material in sample No. 3 from Wood County, Texas. However, only 47 per cent of the benzene-soluble component, or 17 per cent of the total hydrocarbon content, was found to be oil. As the oil fraction was viscous and as the remaining fractions were solids or semi-solids, it is evident that this material can not be produced by present-day methods. The hydrocarbon content of samples No. 1 and No. 2 from Woods County, Texas, were 81 and 90 per cent pyrobitumen, respectively, which probably would plug the pores of the oil sand regardless of the characteristics of the other hydrocarbon fractions.

DISCUSSION

PHOTOGRAPHY OF MEGAFOSSILS1

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J. E. Eaton's paper was worthy of much praise from a photographic standpoint and no doubt may stimulate work by geologists in reproduction photographically of some of the fossils they collect. However, in these days when one can not just go out and buy a camera of the type suggested, one must use what is available. Even in times when camera are being made, but when they are expensive in the larger sizes, many geologists will hesitate to spend the money for a 5×7 -inch camera, and they may even delay in having photos made by commercial photographers.

The effort to make photos of fossil collections is worthwhile, even if the photos are never published, for an album of photos takes so little space that it can be kept and carried around when, in moving, a fossil collection must be scrapped. With this in view, we offer a few suggestions aimed at giving technique whereby an old but available camera may be pressed into service.

Any camera having the specifications here listed may be used in making the photographs, at less than full size if necessary, and the resulting negatives may then be enlarged within reason, say up to five or even more diameters. The writer has a postcard-size camera $(3\frac{1}{4} \times 5\frac{1}{2})$ inches) that has done very good service, and there are many cameras of that size to be had, so one may go ahead with fossil photos even if a larger camera is not available. Even a camera taking $2\frac{1}{4} \times 3\frac{1}{4}$ -inch pictures will be found quite adequate, and there are some miniature cameras that might be pressed into service.

Camera specifications.—The camera must be susceptible of focussing on a ground glass, and of being focussed on an object placed within two focal lengths of the lens or at any greater distance. This requirement means that there must be an extension bellows or equivalent device permitting the lens to be moved out to double the normal focal length; or in the alternative, it must be provided with a lens of half the usual focal length. Some makes of better anastigmat lenses are designed so that one half of the lens may be removed and the other half will serve this purpose. This type of lens is by no means common, but an auxiliary lens may be placed in front of the regular lens, and if it has about the same focal length as the camera lens, it may serve the purpose. The extension bellows is the preferable device, and it should be susceptible of motion toward and from the ground glass. A rack and pinion is preferable, though other device is possible if one has sufficient patience. Most miniature cameras, taking pictures 3 × 4 cm. or 24 × 36 mm., focus by moving the front part of the lens away from the back part as the object approaches the lens. The usual limit of travel will provide only for objects at about 3½ feet distant, and this is too far for much fossil photography. We can not recommend releasing the stop and unscrewing the lens farther, as loss of definition occurs.

The camera must have a diaphragm that will stop down to about 1/10 or 1 inch, but no shutter is essential. If the shutter is worn and unserviceable, but will stay open, there is no harm done for this purpose.

¹ Manuscript received, January 21, 1946. A discussion of the article by Joseph Edmund Eaton, "Photography of Megafossils," published in this Bulletin, Vol. 29, No. 10 (October, 1945), pp. 1494–1511.

² Engineer, Petroleum and Natural Gas Conservation Board.

In focussing, the "circle of confusion" must be kept small, and the size of this circle of confusion is a function of the diameter of the diaphragm opening and the distance of the object from the lens. The writers' postcard-size camera, with a nominal focal length of about 6 inches, stops down to f/64, or to about 1/10 inch, and his miniature camera, with focal length of 2 inches, stops down to f/16 or about $\frac{1}{8}$ inch. Hence the circle of confusion of both cameras is about the same size at about equal distances of object from lens, although the miniature at f/16 is 16 times as fast as the other at f/64. When taking fossils with time exposure, speed is not a great consideration, and the greater distance of the lens from the object is preferable because of improved perspective.

Using the postcard camera, the writer seldom uses full-size film. It has slots for insertion of plate holders, and a piece of cardboard, cut to fit the slot, has a central opening about $\frac{1}{8}$ inch smaller all around than $6\frac{1}{2} \times 9$ cm. cut film. The exact size of the film is then outlined with strips of cardboard stuck in place, so that sheet film may be laid on in the dark. A hood of black paper laid over the camera after placing the film then permits of

exposures made by lighting the object to be photographed.

An item to be noted in taking photos at full size, is that adjustment of the distance of the lens from the ground glass when nearing accurate focus, only changes the size of the image and does not sharpen it. When the object is smaller than the film, set the lens at exactly double its normal focal length and leave it alone, moving the camera in the guillotine frame upward or downward until the focus is right. Inclusion in the field of view of a scale graduated on white material enables one to judge of the degree of enlargement needed to bring a reduced size photo to the natural size. In Plate I, Fig. 2, such a scale is normally trimmed off.

Use of a boxed light as described under the next heading, with no general illumination in the dark room, permits observation in the ground glass without help of a black cloth over the operator's head, since illumination goes entirely on the object being photographed

and its immediate surroundings.

Enlarger.—Once you have a camera that meets the specifications mentioned, and a guillotine frame set up as described by Eaton, all that is needed to complete an enlarger

is a lamp box with receptacle for negative and a holder for bromide paper.

For the postcard camera, the writer had a tinsmith make a tin can 6 inches in diameter by 9 inches high. Its cover has a hole large enough to put the stem of an electric lamp through, and the bottom of the can has central opening $2\frac{1}{4} \times 3\frac{1}{4}$ inches. Soldered below this opening, is a tube, $\frac{1}{4} \times 3\frac{1}{4}$ inches in cross section, 8 inches long, with an opening $2\frac{1}{4} \times 3\frac{1}{4}$ inches across it. Longitudinally through the flat tube two thicknesses of glass, each 3×10 inches, hinged with gummed paper will slide, the negative being placed between them. Finally, a galvanized iron plate, stiff enough to support the weight, is soldered to the flat tube, and this plate slides into the plate holder slots on the camera.

If your camera has no slide provided for insertion of a plate or film pack holder, it may still be possible to remove the back and adapt a sheet metal cover to set over the camera back, shutting out light leaks by use of plush or other similar material, and clipping the

cover firmly to the camera.

A switchless socket laid on the cover of the can is attached with putty, and the putty is given a key to let it hold to the cover by a few nail holes in the tin. The lamp used is a Mazda Photo Enlarger No. 212, 150 watts, opal glass, with no lettering on the end. Just in case there is not adequate diffusion, a flashed opal glass lies about an inch above the bottom of the can, supported by a tin ring having the top edge turned outward. A glass dealer cut the flashed opal glass to a loose fit so that temperature changes will not set up a binding action.

Electric light cord from the enlarger lamp socket is led to a wall switch so placed as to be found easily in the dark, and on a wall or post where operation of the switch will

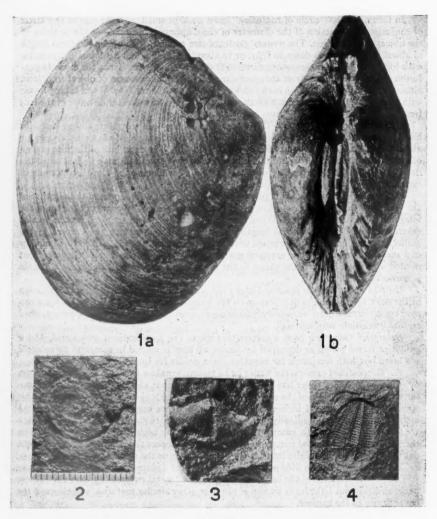


PLATE I

All figures are natural size.

FIG. 1a. Arctica ovata, lateral view. Photographed at about \(\frac{2}{3}\) size and enlarged to full size.

Bulb 212 in box, 2\(\frac{1}{2}\times 3\)\(\frac{1}{3}\) opening, 8-inch distance, cardboard reflector to lighten shadows. XX film f/64, 30 sec. developed in D-76 containing 1 gram potassium bromide to the liter, 18 minutes at 78°F.

Fig. 1b.—Arctica ovata, hinge view. Same lighting, film and exposure. Left half a bit over exposed, and in enlarging, the print was "dodged" to hold back the right half, left half receiving light 2½ times as long as right.

Fig. 2.—Spray River shale containing a poorly preserved ammonite. Relief was very low. Boxed

not jar the camera. The cord goes on from there to a source of electric current. With this 150-watt lamp, and an f/6 lens, it has been possible to make enlargements to 2½ diameters in from 5 to 30 seconds, and thin negatives have sometimes to be stopped down. Greater enlargements take more time in proportion to the area, but it has seldom been necessary to make exposures exceeding three minutes, and excessive temperatures have not been met in that time, although in 15 minutes' consecutive exposure, enough heat accumulates to damage a negative. A 300-watt photo enlarger bulb is made, but if used, some cooling measures for the lamp house would be quite essential.

Illumination of fossils.—Eaton writes of using two photo flood lamps, and then runs into the difficulty of having to use short exposures that must be timed to fractional seconds.

Photo floods have a normal life of about 6 hours, and as they pass about half that period they become blackened and yield a diminishing illumination. The writer's answer is to use a lamp giving less light, but having several hundred hours' life. This saves on a timer, too. Most alarm clocks beat half seconds (time yours against a watch) and tick loudly enough to give audible timing. For exposures of 5 seconds or more, the alarm clock timing is adequate.

For flat fossils having relief of the order of $\frac{1}{6}$ inch, the light from the writer's enlarger lamp box proved desirable, as it makes it possible to cast better shadows. This is a particular advantage when there is no color differentiation in the object. Some fossils lend themselves to use of reflected light rather than to the use of a second lamp. A sheet of white card-board of suitable size, standing vertically behind the fossil will throw a surprising amount of light on the reverse side.

Bromide paper holder.—In making enlargements, the bromide paper is only a bit less sensitive than film, and you must focus on a definitely marked place and then put the paper in that same place. You will have a shelf or table below the camera when taking photos. Provide a board of soft wood to take thumb tacks, and drive three nails to project a bit from the bottom or put rubber headed tacks into the bottom. The board will then stay wherever placed on the shelf. Using several white cards, outline on them 3×4 inches, 4×5 inches, 5×7 inches et cetera. In the corners of each outline, cut a pair of slits a half inch apart so that a strip of scotch tape can be threaded, the sticky side up and the ends stuck on the underside. Fasten a card of the size desired to the board by thumb tacks, project the image and focus carefully. Then lay your bromide paper in place with the enlarger light off and depending on the dark room safe light. The scotch tape holds the back of the paper during exposure and the paper can be lifted for development when exposure has been completed.

Film.—The writer has used professional sheet film in Super-XX Panchromatic successfully, but it must be handled in total darkness, as it is sensitive to all colors of light.

light with no reflector, held low to cast shadows. f/64, 30 sec. Film and development as for Fig. 1a. Scale seen at lower edge was photographed into all exposures as a guide to enlargement and the scale is normally trimmed off.

Fig. 3.—Core from limestone of upper Banff formation, containing Spirifer striatiformis, Warren. Boxed light with reflector of white cardboard. f/64 XX film, 35 sec. Development as for 1a. Upper left printed double the time of lower right. Oblique lighting required to show relief of the sinus.

FIG. 4.—Stephen shale (middle Cambrian) with cast of *Elrathina cordillera*. Boxed light held low owing to small relief; no reflector. f/64 XX film. 60 sec. It is customary to photograph trilobites with head upward, but the relief called for this treatment, with head downward. If the picture is now turned head upward, a false impression is given, the cast appearing to be in raised relief rather than depressed.

Acknowledgment for use of fossils is due to Miss Doris Hewson of the Socony Vacuum staff, for Arctica ovata and Elrathina cordillerae, and she provided the identification. The Spirifer was identified by P. S. Warren from a core supplied by the Highwood Sarcee Oil Company. Super Ortho Press is about as fast as XX and is not sensitive to red, so some red light can be tolerated in the dark room while it is being handled, and this is an advantage. All professional sheet film is on a base stiff enough to stand on edge and to lay in place in an

opening such as has been described.

Most amateur and professional film has quite a latitude of exposure and if all parts of an object are fairly evenly illuminated, there is usually a reproducible image if exposure is within one stop either way from the best. That is, if the best exposure under given light and film conditions is 40 seconds, a printable negative may be obtained with an exposure as short as 20 seconds or as long as 80 seconds. Or, if the best exposure at f/45 is 40 seconds, an acceptable negative may still be had at 40 seconds with aperture of f/64 or f/32.

Thin negatives may still yield good prints by reducing the intensity of light. This is due to the fact that a sensitive paper requires a certain minimum amount of light to fog it, and with reduced intensity of light the high lights of the picture, represented by the most dense part of the negative, do not start to print when the shadows are fully exposed.

Kodalith film differs from other film in its high contrast. The emulsion is very thin, and one tends to get either dead black or transparent film, with small range in between. It is not advised to try to make photos on Kodalith directly from an object, but when a negative is too lacking in contrast to give anything but a muddy print, and when a repeat exposure is out of the question, a Kodalith positive affords a means of bringing out contrast. If the positive is contrasty enough, a negative is then made on normal contrast film and used for paper prints. Another device for increasing contrast even more, is to put a white paper backing under Kodalith (or other film) when making a positive film copy, but be sure the paper is uniformly white. This action is due to reflection of light back into the sensitive emulsion, and a black spot on the reflector will show in the developed film.

Montage.—"Montage" is a term in use among amateur photographers for clipping bits of various pictures, mounting them, and photographing the assembled group. It is suggested that this is a suitable alternative to making the background a dead white by exposing the background separately. When a fossil is white, there is an advantage in making the background black. Montage offers an advantage in making up plates for reproduction in that titles can be added after arranging photos and pasting them on a background, and two photos of the same fossil can be arranged side by side. The montage can be sent

directly to the engraver without rephotographing.

Developing the film.—This is not intended as a treatise on dark room procedure, but it may be in order to mention that hydroquinone, one of the important ingredients of most developers, is inert at temperatures below 60° F. and it becomes increasingly active at increasing temperatures. Hence, a record of temperature of the developer is as important an item as the length of development, 68° F, is recommended, and it pays to watch this. Contrast in the negative is (within limits) a function of time of development, temperature and type of developer being constant. With overexposure, the overexposed parts may actually reverse, giving suggestion of a positive image, and as overexposure is approached, contrast is lost. For reproduction as cuts, much contrast is needed, and this calls for fully developed film. If the result is still muddy, a narrower light source giving more contrast between light and shade is often indicated. Addition of two or three drops of Aerosol to the liter of developer is a good insurance against pinholes in the film caused by failure of the developer to wet the whole surface uniformly. If a film is to be enlarged more than about two diameters, it should be developed in fine-grain developer. This means that more time is consumed in development, for fine grain is attained by slow, restrained reduction of silver in the negative. The added time in development pays dividends handsomely when enlargement is carried to around ten diameters.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

RECENT PUBLICATIONS

ALABAMA

"Geologic Map of the Aliceville, Mantua, and Eutaw Quadrangles, Alabama, Showing Pre-Selma Upper Cretaceous Formations," by D. H. Eargle, W. H. Monroe, and J. H. Morris. U. S. Geol. Survey Prelim. Map. 50, Oil and Gas Investig. Ser. (February, 1946). Prepared with cooperation of the Geological Survey of Alabama and Department of Geology, University of Alabama. Sheet, 40×52 inches. Scale, 1 inch equals 1 mile. Map may be purchased from Director, Geological Survey, Washington 25, D. C. Price, \$0.60.

APPALACHIANS

"New Method of Locating Stratigraphic Traps for Oil and Gas in Appalachian Basin." U. S. Geol. Survey. Results of grain-size analysis of 400 well samples and 300 outcrop samples from oil- and gas-bearing sandstones of Ohio, Pennsylvania, and West Virginia, arranged in tabular form with mimeographed text. Copies obtainable on request from Director, Geological Survey, Washington 25, D. C.

ARGENTINA

*"Argentina's Y.P.F.," by J. Elmer Thomas. Oil Weekly, Vol. 121, No. 1 (Houston, March 4, 1946), International Section, pp. 11-16; photographs.

ARIZONA

*"Black Mesa Area of Northeastern Arizona Is Being Explored for Petroleum Deposits," by Ray E. Colton. *California Oil World*, Vol. 39, No. 4 (Los Angeles, February, 1946), pp. 11–15; 3 figs.

CALIFORNIA

*"West Newport Oil Field," by Carlton Beal and Jan Law. California Oil World, Vol. 39, No. 4 (Los Angeles, February, 1946), pp. 5–9; 3 figs.

CANADA

*"Norman Wells Oil Field," by J. S. Stewart. Oil Weekly, Vol. 121, No. 1 (Houston, March 4, 1946), International Section, pp. 38–52; 3 maps, 2 tables, photograph.

COLOMBIA

*"Eocene Faunas from the Department of Bolivar, Colombia," by Bruce L. Clark and J. Wyatt Durham. *Geol. Soc. America Mem. 16* (New York, February 28, 1946). 126 pp., 28 pls.

COLORADO

*"Rangely Field," by Frank N. Bosco and J. D. Brawner. Oil Weekly, Vol. 120, No. 13 (Houston, February 25, 1946), pp. 18–28; 2 tables, 3 figs., 8 photographs.

GENERAL

*"Oil Migration," by James Frost. *Jour. Inst. Petroleum*, Vol. 31, No. 264 (London, December, 1945), pp. 486-493. This paper was awarded a Students' prize, 1945 (Institute of Petroleum).

*"Graph for Estimating Recoverable Oil by Volumetric Method," by Lyndon L.

Foley. Oil Weekly, Vol. 120, No. 13 (Houston, February 23, 1946), pp. 40-44.

Marine Microbiology. A Monograph on Hydrobacteriology. By Claude E. ZoBell., 240 pp., 12 figs., 40 tables. Published by Chronica Botanica Company, Waltham, Massachusetts (1946); G. E. Stechert and Company, New York City. Cloth. 7×10.5 inches. Price, \$5.00.

"Petroleum Development and Technology, 1945," by the Petroleum Division. Trans.

Amer. Inst. Min. Met. Eng., Vol. 160 (New York, 1946). 666 pp. Price, \$5.00.

*"Functions of Bacteria in the Formation and Accumulation of Petroleum," by Claude

E. ZoBell. Oil Weekly, Vol. 120, No. 12 (February 18, 1946), pp. 30-36.

*"Diccionario y Nomenclatura Geológica en Castellano, Alemán, Ingles" (Dictionary of Geological Nomenclature in Spanish, German, and English), by Heriberto Windhausen. Pub. Didacticas y de Divulgacion Científica de Museo de La Plata No. 3 (La Plata, Argentina, 1945). 203 pp. 6.5×9.5 inches. 14 figs. With German and English index. Contains 1,500 geological terms. Price, \$2.00 U. S. A. Heriberto Windhausen, Casilla Correo No. 8, Yacimientos Petroliferos, Chubut, Argentina.

*"Reflections on the Origin of Oil," by Sylvain J. Pirson. Mineral Industries, Vol. 15,

No. 5 (State College, Pennsylvania, February, 1946), pp. 1, 3, 4.

*"Catalog of the Egan Collection of Silurain Invertebrate Fossils at the Chicago Academy of Sciences," by John R. Ball and Katherine F. Greacen. Chicago Acad. Sci. Spec. Pub. 7 (Chicago, 1946). 55 pp.

KANSAS

*"Geology and Ground-Water Resources of Thomas County, Kansas," by John C. Frye. State Geol. Survey Kansas Bull. 59 (Lawrence, December, 1945). 110 pp., 6 pls., 12 figs., 9 tables.

*"Valley Erosion since Pliocene 'Algal Limestone' Deposition in Central Kansas," by John C. Frye. *Ibid.*, *Bull.* 60, Pt. 3 (Lawrence, December, 1945), pp. 85-100; 1 pl., 2

fies

*"The Cheyenne Sandstone and Adjacent Formations of a Part of Russell County, Kansas," by Ada Swineford and Harold L. Williams. *Ibid.*, *Bull. 60*, Pt. 4, pp. 105-68; 2 pls., 9 figs., 4 tables.

MEXICO

*"Geology of a Part of the Lower Conchos Valley, Chihuahua, Mexico," by Robert E. King and W. S. Adkins. *Bull. Geol. Soc. America*, Vol. 57, No. 3 (New York, March, 1946), pp. 275-304; 4 pls., 2 figs.

MID-CONTINENT

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MISSOURI

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 - "Permian Fusulinids from Afghanistan," by M. L. Thompson.
- "Early Ordovician Cephalopods with Subterminal Apertures," by A. K. Miller and James S. Cullison.
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- "Bibliography and Index to New Genera, Species, and Varieties of Foraminifera for the Year 1944," by Hans E. Thalmann.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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MEMORIAL

ALBERT FOSTER CRIDER (1873-1945)

On September 9, 1945, Shreveport's veteran geologist, Albert Foster Crider, was summoned by death. Though ill in body and several times at death's door during the last quarter of his life, his driving will and his indomitable spirit were unsubdued; his mind remained clear and active to the end. During his long and honorable career he contributed generously to the promotion of geologic thought both through the medium of publication and by word of mouth. His kindly nature, his modest mien and his untiring interest in things geologic endeared him to the hearts of his fellow workers whose friendship he valued highly. Friendship between humans involves the obligation that "one must sometime mourn for the other's death." Surviving friends, join me in a final requiescat in pacem.

Albert Foster Crider, third son of William Bradley Crider and Martha Jane Adams Crider, was born near Marion, Crittenden County, Kentucky, on January 13, 1873. He was educated in the schools of Kentucky, receiving from the State university in 1902 the A.B. degree with geology his major and classics his minor subjects, and, in 1903, the

Bachelor of Science degree in geology.

Following his university career he joined the United States Geological Survey, serving as assistant geologist during the years 1903 to 1905. In this period he performed field work which furnished material for important Federal publications on the clays of western Kentucky and Tennessee, on the geology and mineral resources of Mississippi and on the ground waters of the Arkansas Coastal Plain. In the latter work he was associated with L. W. Stephenson for whose scientific accomplishments he ever after maintained the greatest respect. In 1906 he entered the educational field, for a year occupying the chair of geology at the University of Mississippi. The next step was his appointment as director of the Mississippi Geological Survey where he spent three years studying the mineral resources of the South. In 1912 he returned to Kentucky as assistant State geologist. His energies during the four following years were devoted to an intensive study of coal; his

bibliography reflects the zeal with which he attacked this problem.

The rising tide of petroleum geology, sweeping through the nation in 1916, fascinated Crider; his slight but sinewy craft was soon launched on a voyage of exploration for oil which lasted for almost thirty years. His advent into the oil business was precipitated by an offer from the Atlas Oil Company (later the Palmer Corporation) which firm had started operations in Tulsa sometime before. For four eventful years, 1916 to 1920, he was engaged in geologic investigations throughout the Mid-Continent area for Atlas. A noteworthy success scored in the course of this work was the pre-discovery, surface mapping of the Jennings field in Pawnee County, Oklahoma. Of even greater moment were his observations in Claiborne Parish, Louisiana, where he had early glimpsed some favorable surface evidence west of Homer. O. A. Wright, then manager for the Palmer Oil interests, told this writer many years ago that A. F. Crider's quiet insistence was solely responsible for his company's highly favorable acreage position in the prolific and highly profitable Homer field. Following his success at Homer, Crider—now known far and wide in the industry as "Doc"—stepped into a position with the Dixie Oil Company in Shreveport where from 1920 to 1929 he served that organization well and faithfully, directing its pioneer work in the development of "chalk-rock" oil and in prospecting the then new Glen Rose and Travis Peak zones of Caddo Parish, Louisiana. From 1929 to the end of his career Crider maintained a consulting office in Shreveport. The high regard in which his work was held is evidenced by the fact that though past the allotted three score years



Photograph by Robert Menasco
ALBERT FOSTER CRIDER

and ten he was retained by the Sohio Petroleum Company when that concern launched a vigorous exploratory campaign in the Shreveport territory; the relationship of client and consultant continued until March 15, 1945, only six months preceding the final

Albert Crider was united in marriage with Rosa Rhee Kevil on November 15, 1905. He is survived by Mrs. Crider; by a son, Foster Kevil Crider, who is engaged in geophysical exploration work for W. M. Barret, Inc., in the Shreveport area; by a daughter, Mrs. S.

C. Murray; and by four grand-children.

Crider, the geologist, will be remembered because of the association of his name with the Wilcox group of the Gulf Coast Tertiary section; the group name, which seems destined to retain its place in North American stratigraphy, was introduced in his early bulletins on Mississippi geology. His cooperative, selfless participation in the affairs of the Shreveport Geological Society, of which he was an early president, and of the American Association of Petroleum Geologists, of which he became a member in 1922, is worthy of emulation.

Crider, the man, was held in high esteem as a citizen of Shreveport. He was an active member of the First Presbyterian Church and was a teacher as well as a student of the scripture. His devotion to his native state was traditional; his loyalty to the state of his adoption, sincere and steadfast. The welding of these sentiments is exemplified in his having been chosen to represent the University of Kentucky at the dedication of the new Louisiana State University at Baton Rouge in 1926. His ideals were high; his attainments, memorable. His well rounded life was lived as though the words of Sir Henry Wotton had been its inspiration:

> "How happy is he born and taught, That serveth not another's will; Whose armor is his honest thought And simple truth his utmost skill!"

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C. L. MOODY

SHREVEPORT, LOUISIANA February 21, 1946

FRANK MARION ANDERSON (1863 - 1945)

Dr. Frank M. Anderson died on September 24, 1945, at his home in Berkeley, California, at the age of 82, following a short illness. Nature, whose servant he became, endowed him in the beginning with a strong constitution and an enquiring mind, and thus fitted him for his long and useful work. At the time of his death he was a member of the American Association of Petroleum Geologists, Geological Society of America, Cordilleran Section of American Association for Advancement of Science, Sigma Xi, and was honorary curator of the Department of Paleontology of the California Academy of Sciences.

Frank M. Anderson was born June 4, 1863, near Phoenix, Oregon, the sixth of a family of seven, to Reverend and Mrs. Jesse Marion Anderson, early settlers in the Rogue River Valley from Indiana. Both parents having died while he was a child, he was reared in the home of an uncle-also a pioneer in southern Oregon-and attended the public schools of Ashland. His early interest in natural sciences was evidenced by his collection of minerals and fossils, from the Rogue River Valley, while attending primary schools and in the Klamath country while in Indian Service at Klamath Agency. His technical education began at Willamette University at Salem, Oregon, from which he graduated in 1889. It was while teaching in the grammar schools of Oregon that he received friendly encouragement from Professor Thomas Condon, pioneer geologist of the University of Oregon, and became determined to prepare for the geological profession following his attendance at a lecture by Dr. David Starr Jordan in Portland.

He followed Dr. Jordan to Stanford University and received his A.B. from that institution in 1895. One field season with the United States Geological Survey in Mendocino County as assistant to J. S. Diller and a year's teaching of science in Siskiyou County High School at Yreka preceded his entrance for advanced work in geology at the University of California, from which he received an M.S. degree in May, 1897. He remained in Berkeley as a teaching assistant until appointment as field assistant for the California State Mining Bureau in 1800. Over 30 years later, June, 1030, Stanford University conferred upon him the degree of Ph.D., following his dissertation on "Cretaceous Deposits of Northern Andes"; he thus earned a distinction which has been shared by few men at the age of 67

vears.

In common with the trend of geologic effort at the time, Mr. Anderson's field investigations with the State Mining Bureau were limited to assignments in metalliferous areas of northern California. At the turn of the century little attention was given either in geologic teaching or in the activities of State and Federal surveys to the occurrence of oil in the central and southern part of the State, and to the drilling and producing activities which were gaining momentum in the vicinity of the extensive seepages in the San Joaquin



FRANK MARION ANDERSON

Valley, in Santa Barbara and Ventura counties, and in the Los Angeles Basin. In 1902, and many years before the geological profession was consulted by this new industry on the Pacific Coast, Frank Anderson asked for leave of absence without pay from the State Mining Bureau in order that he might satisfy himself as to the oil possibilities of California. A chance meeting in May of that year, at the breakfast table in McKittrick, with Mr. Josiah Owen—an oil production engineer for the Southern Pacific Railroad Company—led to his employment by that railroad as geologist and a long association with Mr. E. T. Dumble of the Houston, Texas, office of the Southern Pacific Company.

In the period 1902-1911 Mr. Anderson travelled extensively by whatever means were then available throughout the western states under the general assignment of classifying the extensive grant lands and in participation in the development of the natural resources on these lands through the Kern Trading and Oil Company and other agencies. At the beginning of this undertaking very little assistance was available either in the geologic literature or in base maps covering this new and unexplored territory coming under his assignment. With particular attention to the Temblor Range on the west side of the San Joaquin Valley and the Foothill Belt on the east side of the great valley, Mr. Anderson initiated systematic fossil collections and the assemblage of stratigraphic details, organizing for the purpose of his studies and for the dissemination of his data, a department of paleontology in the California Academy of Sciences in San Francisco. As curator of paleontology, 1902-1917, his collections have become the nucleus of a fossil collection which now includes more than half a million catalogued specimens in the present quarters of the Academy in Golden Gate park, Academy publications of 1004 and 1011 contain many contributions by Mr. Anderson to the geologic literature of the Tertiary and Cretaceous of the Pacific Coast, including descriptions of entire new faunas and stratigraphic details which have laid the foundation for subsequent detailed geologic mapping and investigations.

In 1911 Mr. Anderson resigned from the land department of Southern Pacific Railroad and entered the consulting geological field. Noteworthy engagements include exploration and development activities for the Universal Oil Company, 1911–1913; heading an expedition to Colombia for the Standard Oil of New York, 1913–1914; special consultant for the Southern Pacific Land Company in connection with litigation, 1915–1917; and in the organization of a geological department and director of exploration for the General Petroleum Corporation, 1917–1919, in a territory of Canada, the Rocky Mountains, and Mid-Continent in addition to the Pacific Coast. Since 1919, engagements included a second expedition to Colombia for the California Academy of Science and the Tide Water Associated Oil Company; special consultant for the Pan American Petroleum Company, and for the Kettleman North Dome Association. In 1936 Mr. Anderson retired from active economic work and devoted his energies to research and to the completion of various technical writings which had remained unfinished during the busy years as a consultant in which field he had been eminently successful. A keen observer, no details escaped his attention, and aided by a remarkable memory his counsel in the field of exploration or in

the atmosphere of the court room had been equally valuable.

Among the long list of oil discoveries and critical developments with which he has been identified, Buena Vista Hills stands out prominently as a testimonial to his faith in geological field evidence and belief that geological structure was of greater importance in guiding the search for oil fields than the more obvious surface evidence, such as oil seep-

ages, brea deposits, et cetera.

With thoroughness equal to his efforts and successes in economic geology were his studies and contributions in the academic fields of research. A thorough basic training in the allied natural sciences and his own field observations was constantly augmented by wide reading and acquaintanceship with worldwide geologic literature. Mentally equipped to think for himself he created the opportunities to investigate. He knew that he, not someone else, must search out the evidence, no matter how remote at first sight his discovery of fact might appear to be. This search was less difficult because his native sense of humor quickly made friends of men he had never seen, his imagination led him to neglected places, and his photographic memory enabled him to record vividly what he found. He did not scorn the humble origin of a chance truth uttered by the untutored, nor did he accept without question a directive from any source. Always generous in support and encouragement to any worthy cause or individual, he was not sparing in criticism

or denunication of pretense or careless effort. In every sense of the word he was a member of the old school and a firm believer in the fundamentals of his chosen science.

Descriptive writing was Frank Anderson's avocation. Publications on geology and stratigraphy as author or co-author number more than thirty articles or volumes. Better known of his earlier writings include publications in the California Academy of Sciences: "A Stratigraphic Study in the Mt. Diablo Range of California," 1904, "A Further Stratigraphic Study of the Mt. Diablo Range of California," 1908, and "The Neocene Deposits of Kern River, California and the Temblor Basin," 1911. In these pioneering works first appear the names Temblor, Kreyenhagen, Etchegoin, Tulare, and Kern River formations, so effectively identified and described that the names are in use to-day for the major divisions of California Tertiary. Earlier writings, dealing primarily with metalliferous deposits of northern California, include much material about the Cretaceous and Jurassic succession in the Sacramento Valley. Early in 1930 Mr. Anderson, with renewed interest in this great thickness of sedimentary formations, with its rich fossel content, undertook critical studies of the Cretaceous and Jurassic stratigraphy and paleontology on a worldwide basis. With the aid of a grant from the Geological Society of America and the assistance of many field geologists a systematic assembly of material culminated in his "Lower Cretaceous Deposits in California and Oregon," 1938, published as Special Paper No. 16 of the G.S.A. A second volume on the Knoxville of the Pacific Coast is now in press and a third volume on the Chico series was submitted to G.S.A. for publication a short time before his death.

It is to be regretted that Mr. Anderson did not live to see all of his "magnum opus" in final published form, the first volume of which occasioned the highest praises from a wide circle of friends and co-workers in the stratigraphy and paleography of the Mesozoic.

Although duties called him away from home a large part of the time, he maintained a continuous residence in Berkeley where he took an active interest in civic and educational affairs. In 1900 he was married to Elinor Anglin who died in 1916. In 1919 he was married to Theresa M. Barry who survives, as well as their three children, Mrs. Ralph L. MacIntyre, Frances Marion, and Frank Barry, all of Berkeley. In Dr. Anderson's passing his family lost a loving husband and father, the community lost a highly respected citizen, the geological profession lost one of its outstanding members, and the mining and oil industry lost one of its outstanding pioneers in the application of geologic sciences to the finding and development of the earth's natural resources. His published works and the institutions which he initiated evidence a high record of achievement and will ever stand as a memorial to the man who unselfishly devoted so much of his time and energy during the fifty years of professional life, and who contributed so much to a highly creative period in a geological understanding of the two western continents.

C. M. WAGNER

Los Angeles, California February, 1946

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Houston Geological Society Study Group on "Well Logging on the Gulf Coast" has been meeting each Tuesday from 4:30 P.M. until 6:00 P.M. at 1208 Main Street (Humble Building). Lectures, or discussions, on various logging techniques are given each alternating Tuesday by representative authorities on logging methods. The intervening Tuesday meetings are devoted to study, discussion, and preparation of a paper on the various methods of logging by the group. Recent lectures are the following: "Mud Analysis Logging," by B. Otto Pixler of the Baroid Sales Company; "Caliper Logging," by H. Guyod, consulting; and "Geochemical and Temperatures Logging," by H. Guyod.

The Houston Geological Society held a regular luncheon meeting, March 11, at the Texas State Hotel, at which W. Armstrong Price, consulting geologist of Corpus Christi, gave a paper entitled "Quaternary and Recent Evidences of Diastrophism in the Gulf Coastal Area."

JACK W. DAVIES is again at Shawnee, Oklahoma, with the Halliburton Oil Well Cementing Company after returning from the service.

ARTHUR IDDINGS has changed his address from Caracas, Venezuela, to Rio Venado Farms, Darlington, Maryland.

C. G. Carlson, consulting geologist of Tulsa, Oklahoma, has returned after 3 months of special work in Colombia, South America.

After nearly 4 years as chief of the Forest and Mineral Product Section of Supply and Resources Service, FEA, H. W. Straley, III, has retired from Government. While, with FEA, he has concentrated on western Canada, China, the Middle East, West Africa, Ethiopia, and the Balkan region, as well as Latin America. He has opened consulting offices in Washington where he will specialize in geological and geophysical exploration of mining and oil properties in the Appalachian region, the Atlantic coastal plain, and the Caribbean. He may be addressed, 5532 Friendship, Washington 16, D. C.

FRANK M. BROOKS, resigned as head of the geological department for the Bridgeport Oil Company, Inc., effective the first part of March, to accept a position of similar capacity with the El Dorado Refining Company, El Dorado, Kansas.

Frank S. Hudson has left the Yuba Consolidated Gold Fields. His home address is still 3036 Divisadero Street, San Francisco, California.

Lyman C. Dennis, of the Pure Oil Company, has been transferred from Jackson, Mississippi, to Wichita Falls, Texas, where he is district geologist, replacing Melvin D. Mauck, who is transferred to Midland, Texas. John N. Huff, Jr., formerly at Shreveport, Louisiana, replaces Dennis as district geologist in Jackson.

W. D. Anderson, formerly with the Amerada Petroleum Corporation, is now a member of the firm of Anderson, Huffman, and Johnson, consulting geologists, Midland, Texas.

ALBERT W. Musgrave, Hugo, Colorado, was discharged from the Navy on March 3 and is resuming his study at the Colorado School of Mines, Golden.

QUENTIN D. SINGEWALD, has resigned from his teaching position at the University of Rochester, New York state, to remain with the United States Geological Survey. Since

1942 he has been in South America; the last 6 months' assignment was in Bolivia to appraise the tin resources.

JOHN H. FACKLER has been assistant geologist with the Chanslor-Canfield Midway Oil Company for the past year. His address is 1209 East Main Street, Ventura, California.

RICHARD P. GOLDTHWAIT, formerly of Brown University and during the war in charge of special equipment investigations for the Army Air Corps at Wright Field, has been appointed associate professor of geology at the Ohio State University, where EDMUND M. SPIEKER is chairman of the department of geology.

O. F. Evans, professor of geology from the University of Oklahoma, gave a lecture on "Bars, Spits, and Ripple Marks and the Methods of Formation" at a meeting of the Shawnee Geological Society in the Aldridge Hotel on March 7, 1946.

ROBERT E. KING has moved from the New Orleans office of The Texas Company to become district geologist for that company in Jackson, Mississippi, succeeding R. R. PRIDDY, who resigned from The Texas Company to accept the position of head of the department of geology at Millsaps College in Jackson.

CHARLES M. Cross, until recently with the Tide Water Associated Oil Company, is now with the geological staff of the Honolulu Oil Corporation in San Francisco. He recently returned from 5 years service in the Army where he was a colonel in the Ordnance Department.

ROBERT N. WILLIAMS, recently released from 3 years service in the Army Engineers Corps as a major, has returned to geological work with Honolulu Oil Corporation and is in charge of their newly established office in the Benjamin Franklin Building, Santa Barbara, California.

JOSEPH M. GORMAN is with the Creole Petroleum Corporation, Apartado 889, Caracas, Venezuela.

The executive committee of the Association, in meeting at Chicago, February 28, elected the following to honorary membership in the Association: WILLIAM HARVEY EMMONS, of the Department of Geology, University of Minnesota, Minneapolis, and Elias Howard Sellards, of the Bureau of Economic Geology, University of Texas, Austin.

The Association Medal Award committee has named Horace G. Richards, of the Academy of Natural Sciences, Philadelphia, as the recipient of the President's award in 1945. The selection was made for the winner's article, "Subsurface Stratigraphy of Atlantic Coastal Plain between New Jersey and Georgia," published in the July, 1945, Bulletin.

A free copy of the *Interim Proceedings*, Part 1, of the Geological Society of America, 1946, containing the "Conference Report on International Inspection of Radioactive Mineral Production," by the Carnegie Endowment committee on inspection of raw materials, may be had on request. Write Henry R. Aldrich, secretary, Geological Society of America, 419 West 117th Street, New York, N. Y., or A.A.P.G. Headquarters, Box 979, Tulsa 1, Oklahoma.

CARROLL H. WEGEMANN described "Life in Old Mexico" at the meeting of the Rocky Mountain Association of Petroleum Geologists, at the Shirley Savoy Hotel, Denver, Colorado, March 18.

WATSON H. MONROE, United States Geological Survey, Washington, D. C. has com-

pleted his part of the assignment studying the stratigraphy of the pre-Selma rocks of Alabama and is now making a similar study of the Woodbine of Texas.

James R. Day, previously with the Amerada Petroleum Corporation at Midland, has accepted the position of district geologist with the Pan American Production Company at Abilene, Texas.

NICHOLAS W. SHIARELLA, of the firm of Miller and Shiarella, died at Owensboro, Kentucky, March 14, at the age of 48 years.

GEORGE B. SAMMONS, independent geologist of Wichita, Kansas, died on January 14, at the age of 58 years.

W. W. HAMMOND and J. S. WOODWARD, of the Magnolia Petroleum Company, read a paper at the meeting of the South Texas Section of the Association, of San Antonio, March 26.

Through its nomenclature committee, the Wyoming Geological Association has prepared a list of structure names of Wyoming. This list is as complete as it can be made, and its chief purpose is to eliminate duplications in naming future prospects. For this reason it is hoped it will have a wide distribution among those operators who are interested in Wyoming. The list shows names alphabetically; the county, and township and range are also given. An attempt has been made to show which structural names are synonymous. Multilithed copies may be secured from the secretary-treasurer, Wyoming Geological Association, Box 545, Casper, Wyoming, at fifty cents a copy.

F. W. Floyd has been made manager of the foreign department and elected executive vice-president of the foreign subsidiaries of the Phillips Petroleum Company, succeeding D. R. Knowlton. His headquarters office is in Caracas, Venezuela.

M. M. SHEETS, Stanolind Oil and Gas Company, spoke on "Diastrophism during Historic Time in the Gulf Coastal Plain," at a meeting of the Houston Geological Society, March 25.

HOWARD A. GIBSON has left the employment of V. C. Perini, Jr., and is now with the Pan American Production Company, as geologist at Abilene, Texas.

Officers of the Southeastern Geological Society, Box 841, Tallahassee, Florida, are: president, I. J. Reed, The California Company; vice-president, Walter B. Jones, Geological Survey of Alabama; secretary-treasurer, H. A. Sellin, Magnolia Petroleum Company.

ODELL C. "Doc" OLSON, on inactive duty status with the United States Marine Corps, is now a petroleum engineer with the Railroad Commission of Texas at Midland, Texas.

The following are the new officers of the Michigan Geological Society for the year 1946: president, Rex P. Grant, Michigan Geological Survey, Capitol Savings and Loan Building, Lansing; vice-president, Richard H. Wolcott, Sohio Petroleum Company, 601 South Main Street, Mt. Pleasant; secretary-treasurer, Charles K. Clark, Pure Oil Company, 402 Second National Bank Building, Saginaw; business manager, Kenneth Gravelle, Gulf Refining Company, Box 811, Saginaw.

Captain ROBERT T. POLLARD has recently returned to the United States after serving in Panama, Hawaii, Okinawa and Korea. He may be addressed c/o Alexander and Pollard, consulting engineers and geologists, 414 Terminal Building, Oklahoma City, Oklahoma.

The guest speaker of the New Orleans Geological Society on March 18, was Lieutenant Colonel Charles M. Thomas, superintendent of the southern district of the United States Coast and Geodetic Survey. The subject of his illustrated lecture was "Hydrographic surveys in the Gulf of Mexico."

The National Service Committee has been continued with Gordon Gulley, Chairman. The members will be announced later.

The committee on Boy Scout literature has been continued with Max Ball, Chairman.

CHICAGO

Thirteen hundred members and friends registered at the joint annual meeting of the three petroleum exploration societies at Chicago, April 1-4. This was the occasion of the 31st annual meeting of the A.A.P.G., the 20th annual meeting of the S.E.P.M., and the 16th annual meeting of the S.E.G. Featuring this first meeting after the war were A.A.P.G. sessions on the Application of Geology to Military Science, the Reviews of Trends and Developments since 1941, papers on Tectonics, and conferences on Research Papers on the geologists' program numbered 40 by oral delivery and 23 printed by title. The paleontologists' program contained 28 papers, and the geophysicists' 33.

EUGENE HOLMAN, president of the Standard Oil Company (New Jersey), addressed the meeting on the night of April 2. The dinner-dance was held on April 3.

President Monroe G. Cheney presented certificates of membership to two new honorary members of the Association: W. H. Emmons, of the University of Minnesota, and E. H. SELLARDS, of the University of Texas. He also presented the President's award for the most significant paper in the 1945 Bulletin to H. G. RICHARDS, of the Academy of Natural Sciences, Philadelphia.

Association officers nominated and unanimously elected at Chicago to serve during the new administrative year are the following:

President: EARL B. NOBLE, Union Oil Company of California, Los Angeles.

Vice-President: D. PERRY OLCOTT, Humble Oil and Refining Company, Houston,

Secretary-Treasurer: EDWARD A. KOESTER (re-elected), Darby and Bothwell, Inc., Wichita, Kansas.

Editor: GAYLE SCOTT (re-elected), Texas Christian University, Fort Worth, Texas.

The outgoing president of A.A.P.G. is Monroe G. Cheney, Anzac Oil Corporation, Coleman, Texas; the outgoing vice-president is M. Gordon Gulley, Gulf Oil Corporation, Pittsburgh, Pennsylvania; and the outgoing past-president is IRA H. CRAM, Pure Oil Company, Chicago, Illinois.

The membership of the A.A.P.G., as of March 1, 1946, numbers 4676, representing a new high net increase of 350 over the total of the preceding year. Of this total, 423 reside outside the United States.

Incoming officers of the Society of Economic Paleontologists and Mineralogists are: President: F. W. Rolshausen, Humble Oil and Refining Company, Houston, Texas. Vice-President: CECIL G. LALICKER, University of Oklahoma, Norman, Oklahoma.

Secretary-Treasurer: H. B. STENZEL, University of Texas Bureau of Economic Geology, Austin, Texas.

Incoming officers of the Society of Exploration Geophysicists are:

President: J. J. JAKOSKY, University of Southern California, Los Angeles.

Vice-President: CECIL H. GREEN, Geophysical Research, Inc., Dallas, Texas.

Secretary-Treasurer: GEORGE E. WAGONER, Carter Oil Company, Tulsa, Oklahoma.

Editor: L. L. NETTLETON (re-elected), Gulf Research Laboratory, Pittsburgh, Pennsylvania.

CHANGES IN CONSTITUTION

In accordance with the action of the Association in annual meeting at Chicago, April 4, ballots will shortly be mailed to all members for voting on amendments to the Constitution to put into effect the proposed changes in the method of election of officers, and for voting on a change in the code of ethics. Ballots must be returned within 90 days of their mailing in order to be counted.

LOS ANGELES, MARCH, 1947

The executive committee of the Association, in meeting at Chicago, April 4, accepted the invitation of the Pacific Section to hold the 32d annual meeting in Los Angeles, California, in the week beginning March 24, 1947. The Biltmore Hotel, Los Angeles, has been selected as convention headquarters.

NOTICE OF PUBLICATION OF HEARINGS ON NEW SOURCES OF PETROLEUM IN THE

New Sources of Petroleum in the United States is the subject of a volume of hearings of the Senate Special Committee Investigating Petroleum Resources which will go to the press at the Government Printing Office within the next week or ten days. This volume contains the record of the proceedings of the Committee from June 19 to June 25, 1945, when the testimony of the leading petroleum experts of the country from the circles of industry, as well as from the Government, presented the latest information on the occurrence of petroleum in the United States. The information contained in this volume will be invaluable to all persons interested in American industry, for petroleum is the principal fuel of the machine age.

The Superintendent of Documents advises me that this volume, containing approxi-

mately 550 pages, will be placed on sale at 75¢ per copy.

I make this announcement because the demand for copies is expected to exceed the limited supply made available to the Committee. It would be advisable, therefore, particularly for persons who desire extra copies to place their orders immediately with the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C.

JOSEPH C. O'MAHONEY, chairman Special Committee Investigating Petroleum Resources

Washington, D. C. March 12, 1946

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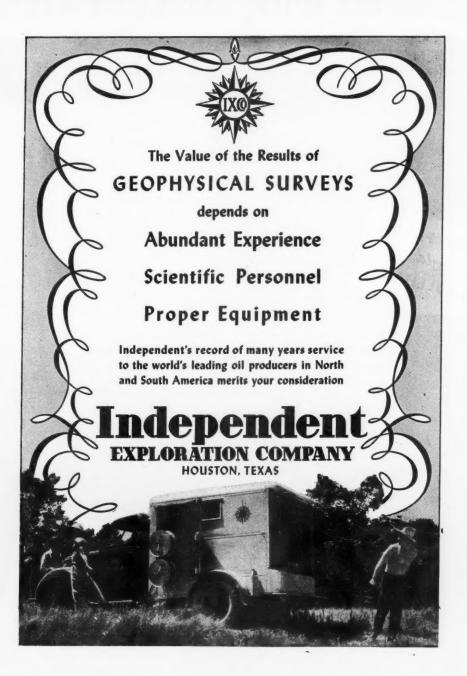
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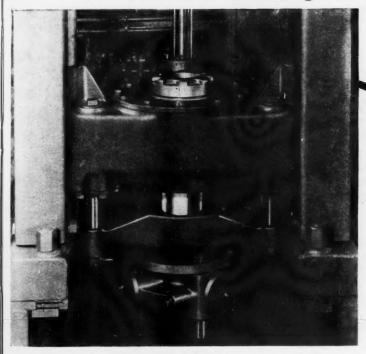
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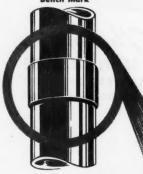
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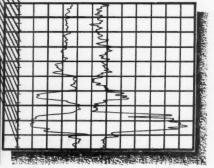
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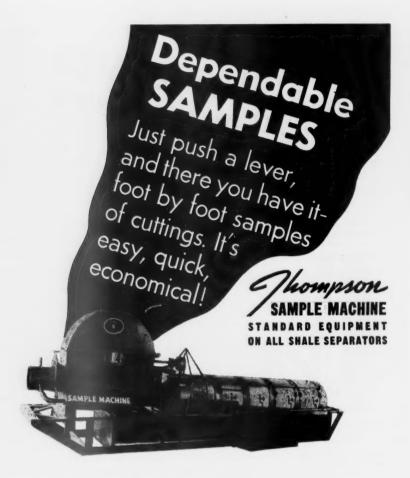
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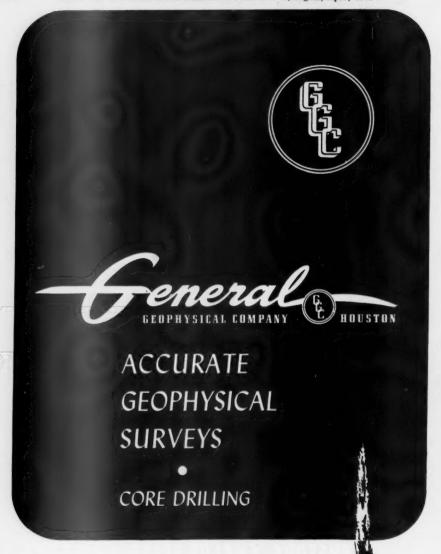


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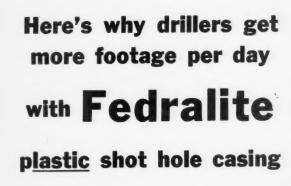
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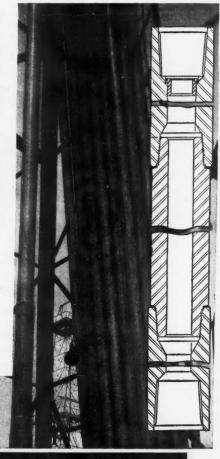


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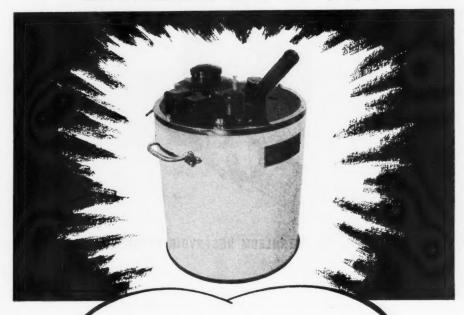


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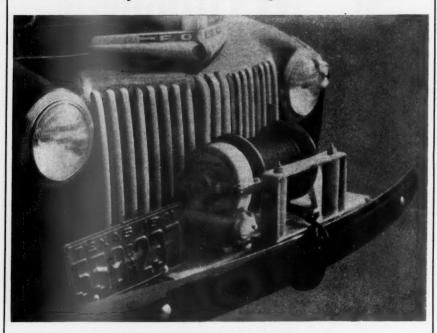
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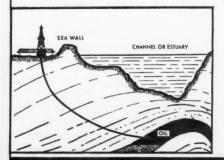
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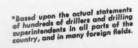
ways. That's wrong. They're two entirely different methods. And the methods and equipment used in one won't work in the other—just remember that!

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